Exhibit 57

Hydrogen Sulfide, Oil and Gas, and People's Health

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1. Introduction

This paper documents impacts on human health caused by exposure to hydrogen sulfide (H_2S) associated with oil and natural gas development. I begin with a brief background on hydrogen sulfide, its presence in oil and natural gas, and possible emission sources from various oil and gas operations. I then present a review of literature[1] from available public health, epidemiology, and industrial health publications, as well as of sources from regulatory and environmental agencies, that addresses human health impacts from exposure to H_2S. The Literature Review section first covers studies of health effects from acute exposure to relatively high concentrations of H_2S. I then review the literature documenting human health effects from chronic exposure to lower ambient H_2S levels. Both kinds of exposure – acute and chronic – can be expected to occur near oil and gas operations. From the available sources, I construct a table of human health effects associated with different levels of hydrogen sulfide and different lengths of exposure. Reviewing studies on the effects of H_2S exposure on laboratory animals is beyond the scope of this study.

Next, I present current federal and state regulations and recommendations pertaining to exposure to hydrogen sulfide. Many recommendations established to protect human health are based on crude exposure estimates or on extrapolation from animal studies. The federal government does not regulate ambient H_2S levels, but many states do. Three states conduct routine monitoring of ambient H_2S levels, and several others have monitored H_2S as part of specific projects. I present the available monitoring data, as well as anecdotal evidence about H_2S emissions and human health concerns that I obtained from conversations with staff at state environmental agencies.

[1] I searched on-line catalogs including Web of Science and Environmental Sciences and Pollution Management, and tracked down relevant references listed within each article.

The final component of my research consists of informal interviews with people living near oil and gas operations who have been, or believe they have been, exposed to hydrogen sulfide and believe they are experiencing adverse heath effects due to exposure. Enough evidence emerges from literature searches and reviews, environmental health professionals, available monitoring data, and personal stories to warrant more research. Although the evidence is patchy, the potential for health risks is real and the stakes are high. More monitoring and regulation are required to adequately protect human health.

2. Hydrogen Sulfide in the Environment

Approximately 90 percent of the sources that emit hydrogen sulfide into the air are natural.[2] Hydrogen sulfide is released into the air as a product of the decomposition of dead plant and animal material,[3] especially when this occurs in wet conditions with limited oxygen, such as in swamps. Hot springs, volcanoes, and other geothermal sources also emit H_2S.

Anthropogenic releases of H_2S into the air result from industrial processes, primarily from the extraction and refining of oil and natural gas and from paper and pulp manufacturing,[4] but the gas is also present at sewage treatment plants, manure-handling plants, tanneries, and coke oven plants.[5]

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[2] EPA, "Report to Congress on Hydrogen Sulfide Air Emissions Associated with the Extraction of Oil and Natural Gas." EPA-453/R-93-045, October 1993. " p.III-4.
[3] Decomposition of dead organic matter (DOM) by fungi, actinomycetes, and bacteria releases hydrogen sulfide from sulfur-containing proteins and from the direct reduction of sulfate (SO4+).
[4] New York State Department of Health: available at http://www.health.state.ny.us/nysdoh/environ/btsa/sulfide.htm
[5] "Public Health Statement for Hydrogen Sulfide," Agency for Toxic Substances and Disease, September 2004. Available at http://www.atsdr.cdc.gov/toxprofiles/tp114-c1.pdf

3. Hydrogen Sulfide and Oil and Gas

Hydrogen sulfide is a naturally occurring component of crude oil and natural gas. Petroleum oil and natural gas are the products of thermal conversion of decayed organic matter (called kerogen) that is trapped in sedimentary rocks. High-sulfur kerogens release hydrogen sulfide during decomposition, and this H_2S stays trapped in the oil and gas deposits.[6]

Methane (CH_4) is the predominant component of natural gas, comprising 70 to 90 percent, while other gaseous hydrocarbons, butane (C_4H_{10}), propane (C_3H_8), and ethane (C_2H_6), account for up to 20 percent. Contaminants present in natural gas, which have to be removed at natural gas processing facilities, include water vapor, sand, oxygen, carbon dioxide, nitrogen, rare gases such as helium and neon, and hydrogen sulfide.[7] In fact, hydrogen sulfide is the predominant impurity in natural gas.[8] The Environmental Protection Agency (EPA) classifies natural gas as *sour* when H_2S is present "in amounts greater than 5.7 milligrams per normal cubic meters (mg/Nm^3) (0.25 grains per 100 standard cubic feet)."[9]

Sour gas is routinely 'sweetened' at processing facilities called desulfurization plants. Ninety five percent of the gas sweetening process involves removing the H_2S by absorption in an amine solution, while other methods include carbonate processes, solid bed absorbents, and physical absorption.[10]

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[6] EPA "Report to Congress on Hydrogen Sulfide Emissions", p.II-1.
[7] *Oil and Gas at Your Door? A landowner's guide to oil and gas development*. OGAP 2005. p.I-2.
[8] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.II-i.
[9] Environmental Protection Agency, AP 42, Fifth Edition, Volume I, Chapter 5: The Petroleum Industry, available at http://www.epa.gov/ttn/chief/ap42/ch05/final/c05s03.pdf
[10] EPA, "Petroleum Industry." P.5.3-1. For details on these and other technologies for 'sweetening' sour gas, see "Crystasulf Process for Desulfurizing Ultra-deep Natural Gas Near the Wellhead," presented at *Natural Gas Technologies II Conference and Exhibition,* February 2004. Phoenix, AZ. Ref. No. T04135. pp.5-9.

Between 15 to 25 percent of natural gas in the U.S. may contain hydrogen sulfide,[11] while worldwide, the figure could be as high as 30 percent. The exact number of sour wells in the United States is not known, though natural gas deposits in Arkansas, southeastern New Mexico, western Texas, and north-central Wyoming have been identified as sour.[12] Hydrogen sulfide occurs naturally in the geologic formations in the Rockies, the Midcontinent, Permian Basin, and Michigan and Illinois Basins.[13] As more natural gas development occurs in these areas, it is likely that the number of sour wells will increase, because new drilling is increasingly focused on deep gas formations that tend to be sour.[14] Although exact statistics on sour wells are not available, the EPA concedes that "the potential for routine H_2S emissions [at oil and gas wells] is significant."[15]

The most comprehensive source on the distribution of sour gas is a report prepared by consultants for the Gas Technology Institute, formerly Gas Research Institute, a research, development, and training organization that serves the natural gas industry.[16] This report states that "Regions with the largest percentage of proven reserves with at least 4 ppm hydrogen sulfide are Eastern Gulf of Mexico (89 percent), Overthrust (77 percent), and Permian Basin (46

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[11] Dalrymple, D.A., Skinner, F.D. and Meserole, N.P. 1991. *Investigation of U.S. Natural Gas Reserve Demographics and Gas Treatment Processes.* Topical Report, GRI-91/0019, Section 3.0, pp. 3-1 to 3-13. Gas Research Institute. And Hugman, R.H., Springer, P.S. and Vidas, E.H. *Chemical Composition of Discovered and Undiscovered Natural Gas in the United States: 1993 update*. Topical Report, GRI-93/0456. p. 1-3. Gas Research Institute. As cited in McIntush, K.E., Dalrymple, D.A. and Rueter, C.O. 2001. "New process fills technology gap in removing H2S from gas," *World Oil*, July, 2001.

[12] EPA, "Report to Congress on Hydrogen Sulfide Emissions". p. I-3.

[13] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p. I-3.

[14] Quinlan, M., 1996. "Evaluation of selected emerging sulfur recovery technologies," *GRI Gas Tips*, 3(1):26-35. In McIntush, K.E., Dalrymple, D.A. and Rueter, C.O. 2001. "New process fills technology gap in removing H2S from gas," *World Oil*, July, 2001.

[15] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-35.

[16] Energy and Environmental Analysis, Inc. for Gas Research Institute, "Chemical Composition of Discovered and Undiscovered Natural Gas in the Lower-48 United States," GRI 90/0248. November 1990. (mailed to me by librarian for Gas Technology Institute).

percent)."[17] Figure 1 illustrates the major H_2S prone areas in the United States and identifies the basins.

Figure 1. ***Map of Major H_2S-prone Areas in the Continental United States***[18]

4. Hydrogen Sulfide Emissions from Oil and Gas Facilities

There has been some investigation of hydrogen sulfide emissions associated with oil and gas development.[19] In the Literature Review section, I summarize several studies that researched H_2S emissions near oil and gas facilities. Several states' environmental departments have monitored H_2S concentrations near oil and gas operations. My conversations with personnel at these agencies confirm that there are H_2S emissions associated with oil and gas activities. I present the evidence from the state studies and my conversations with staff in the State Regulations section. Finally, the interviews I conducted with people living near oil and gas

[17] Energy and Environmental Analysis, Inc. for Gas Research Institute. pp.2-3.
[18] Energy and Environmental Analysis, Inc. for Gas Research Institute. p.1-13 and p.A-5.
[19] For example, Environmental Protection Agency, "Report to Congress on Hydrogen Sulfide Air Emissions Associated with the Extraction of Oil and Natural Gas." EPA-453/R-93-045, October 1993. and Tarver, Gary A. and Purnendu K. Dasgupta. "Oil Field Hydrogen Sulfide in Texas: Emission Estimates and Fate." *Environmental Science and Technology*. **31**: (12) 3669-3676. 1997.

sites attest to the presence of H_2S in the ambient air. Detailed narratives of the interviews are in Appendix D.

Oil and gas operations may emit hydrogen sulfide, routinely or accidentally, during the extraction, storage, transport, or processing stage.[20] During of extraction, hydrogen sulfide may be released into the atmosphere at wellheads, pumps, piping, separation devices, oil storage tanks, water storage vessels, and during flaring operations.[21] Flares burn gases that cannot be sold as well as gases at points in the system where operating problems may occur, as a safety measure. Because it cannot be sold, hydrogen sulfide is routinely flared. Sulfur dioxide (SO_2) is the product of combusting hydrogen sulfide, but in the event of incomplete combustion, H_2S may be emitted into the atmosphere.

Based on reviewing the available literature and the records of agencies to which accidental releases of hydrogen sulfide might be reported,[22] the EPA states that well blowouts, line releases, extinguished flares, collection of sour gas in low-lying areas, line leakage, and leakage from idle or abandoned wells are sources of documented accidental releases that have impacted the public, not just workers at of oil and gas extraction sites.[23] Well blowouts are uncontrolled releases from wells, and can occur during drilling, servicing, or production, as a result of a failed 'blowout preventer' during drilling or a failed subsurface safety valve during

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[20] *Schlumberger Oilfield Glossary*, available at http://www.glossary.oilfield.slb.com/default.cfm

[21] EPA "Report on Hydrogen Sulfide Air Emissions," P.II-6. See Section II, pp.3 to 10 for details. A wellhead is the first piece of equipment where the oil leaves the ground. Pumps that extract the oil may leak at the seals. Piping connects the various machinery and storage units at an oil pad. Separation devices separate oil from gas and water, and pipes take the gas to a dehydrator, while other pipes direct water and oil to a heater-treater where the two are separated. The oil is then piped into an oil storage tank, and the water is piped into a produced water storage tank. Wellheads, pipes, and separation devices may leak hydrogen sulfide because of corrosion and embrittlement caused by the reaction of water with metal and H_2S, or due to poor maintenance and poor materials. The heater-treaters may release hydrogen sulfide due to high pressures or pressure changes above design specifications. Oil storage tanks may release hydrogen sulfide as a result of day-night temperature changes, volatilization, and filling operations. Produced water storage vessels may contain hydrogen sulfide dissolved in water that is brought up from the reservoir, or it may be produced by sulfate-reducing bacteria found in water and oil.

[22] State agencies, emergency response organizations, industry officials. EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-36.

[23] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-38.

production.[24] The release from a well blowout can last for an indefinite period.[25] After all economically recoverable oil and gas has been removed, the well needs to be plugged, or sealed. If a well is improperly sealed, hydrogen sulfide may routinely seep into the atmosphere. One study, discussed below, documented precisely this type of hydrogen sulfide emissions in Whaler's Cove, a community in Long Beach, California, where a townhouse development was built on a 1940s oil field. Additionally, hydrogen sulfide may be routinely or accidentally released into the atmosphere at oil refineries and natural gas processing facilities, including desulfurization plants.

Hydrogen sulfide emissions from oil and gas development may pose a significant human health risk, as the studies discussed below reveal. Workers in the oil and gas industry are trained to recognize and respond to high-concentration accidental releases of H_2S. The American Petroleum Institute (API), an oil and gas industry technical organization, publishes recommendations for practices that help prevent hazardous H_2S concentrations from occurring in the workplace.[26] People living near oil and gas development sites may be chronically exposed to much lower, but nonetheless dangerous ambient H_2S levels, as well as to accidental high-concentration releases. A 1993 EPA report on the emissions of hydrogen sulfide from oil and gas extraction acknowledges that because of the proximity of oil and gas wells to areas where people live, the affected population may be large.[27]

Additionally, the "Public Health Statement for Hydrogen Sulfide," a public health advisory summarizing the longer H_2S Toxicological Profile issued by the Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry (ATSDR),

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[24] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-45.
[25] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-49.
[26] API Recommended Practice (RP) 54, *Recommended Practice for Occupational Safety for Oil and Gas Well Drilling and Servicing Operations* and API RP 49, *Safe Drilling of Wells Containing Hydrogen Sulfide*.
[27] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-65.

acknowledges that "As a member of the general public, you might be exposed to higher-than-normal levels of hydrogen sulfide if you live near a waste water treatment plant, a gas and oil drilling operation, a farm with manure storage or livestock confinement facilities, or a landfill. Exposure from these sources is mainly from breathing air that contains hydrogen sulfide."[28] The ATSDR also reports that higher than normal ambient "levels [of hydrogen sulfide] (often exceeding 90 ppb) have been detected in communities living near natural sources of hydrogen sulfide or near industries releasing hydrogen sulfide."[29]

5. Human Health Effects from Exposure to Hydrogen Sulfide

Human health effects of exposure to hydrogen sulfide, an irritant and an asphyxiant, depend of the concentration of the gas and the length of exposure. Background ambient levels of H_2S in urban areas range from 0.11 to 0.33 ppb, while in undeveloped areas concentrations can be as low as 0.02 to 0.07 ppb.[30] A rotten egg odor characterizes H_2S at low concentrations, and some people can detect the gas by its odor at concentrations as low as 0.5 ppb.[31] About half of the population can smell H_2S at concentrations as low as 8 ppb, and more than 90% can smell it at levels of 50 ppb.[32] Hydrogen sulfide, however, is odorless at concentrations above 150 ppb, because it quickly impairs the olfactory senses.[33] Prolonged exposure to concentrations below

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[28] "Public Health Statement for Hydrogen Sulfide," Agency for Toxic Substances and Disease, September 2004. Available at http://www.atsdr.cdc.gov/toxprofiles/tp114-c1.pdf
[29] ATSRD, Ch2, p.1.
[30] Agency for Toxic Substances and Disease Registry (ATSDR). 2004. Toxicological profile for hydrogen sulfide (*Draft for Public Comment*). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Chapter 2, p.1.
[31] New York State Department of Health: available at http://www.health.state.ny.us/nysdoh/environ/btsa/sulfide.htm
[32] Collins, P. and Lewis, L. 2000. *Hydrogen Sulfide: Evaluation of Current California Air Quality Standard with Respect to Protection of Children.* Prepared for California Air Resources Board and California Office of Environmental Health Hazard Assessment. In: Summary of the toxicity assessment of hydrogen sulfide conducted by the Secretary's Scientific Advisory Board on Toxic Air Pollutants. http://daq.state.nc.us/toxics/studies/H2S
[33] Knight, Laura D., MD, and S. Erin Presnell, MD. 2005. "Death by Sewer Gas: Case Report of a Double Fatality and Review of the Literature." *The American Journal of Forensic Medicine and Pathology*. p.183.

150 ppb can also cause olfactory fatigue.[34] This effect of disabling the sense of smell at levels that pose serious health risks and possibly are life-threatening is one especially insidious aspect of hydrogen sulfide exposure. Odor is not necessarily a reliable warning signal of the presence of H_2S.

Most effects to humans occur from inhalation, though exposure generally also affects the eyes. Because most organ systems are susceptible to its effects, hydrogen sulfide is considered a broad spectrum toxicant.[35] The organs and tissues with exposed mucous membranes (eyes, nose) and with high oxygen demand (lungs, brain) are the main targets of hydrogen sulfide.[36] Hydrogen sulfide acts similarly to hydrogen cyanide, interfering with cytochrome oxidase and with aerobic metabolism.[37] Essentially, hydrogen sulfide blocks cellular respiration, resulting in cellular anoxia, a state in which the cells do not receive oxygen and die. The human body detoxifies hydrogen sulfide by oxidizing it into sulfate or thiosulfate by hemoglobin-bound oxygen in the blood or by liver enzymes.[38] Lethal toxicity occurs when H_2S is present in concentrations high enough to overwhelm the body's detoxification capacity.[39]

At levels up to 100 to 150 ppm, hydrogen sulfide is a tissue irritant, causing keratoconjunctivitis (combined inflammation of the cornea and conjunctiva), respiratory irritation with lacrimation (tears) and coughing.[40] Skin irritation is also a common symptom. Instantaneous loss of consciousness, rapid apnea (slowed or temporarily stopped breathing), and

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[34] Glass, D.C. "A Review of the Health Effects of Hydrogen Sulphide Exposure." *Annals of Occupational Hygiene*. 34:(3) p.323.
[35] Legator, Marvin S., et al.. "Health Effects from Chronic Low-Level Exposure to Hydrogen Sulfide." *Archives of Environmental Health*. **56:** (2) 123-131. March/April 2001. p.124.
[36] Legator, Marvin S., et al.. p.124.
[37] Knight, Laura D., MD, and S. Erin Presnell, MD. 2005. "Death by Sewer Gas: Case Report of a Double Fatality and Review of the Literature." *The American Journal of Forensic Medicine and Pathology*. p.183.
[38] Knight, 2005. p.184.
[39] Knight, 2005. p.184.
[40] Knight, 2005. p.183.

death may result from acute exposure to levels above 1,000 ppm.[41] At these higher levels, hydrogen sulfide is an asphyxiant.

The non-lethal effects can be summarized as *neurological* – consisting of symptoms such as dizziness, vertigo, agitation, confusion, headache, somnolence, tremulousness, nausea, vomiting, convulsions, dilated pupils, and unconsciousness, and *pulmonary* – with symptoms including cough, chest tightness, dyspnea (shortness of breath), cyanosis (turning blue from lack of oxygen), hemoptysis (spitting or coughing up blood), pulmonary edema (fluid in the lungs), and apnea with secondary cardiac effects.[42]

Table 1 lists the health effects associated with H_2S exposures of varying durations. The table reports health effects that toxicological and epidemiological studies have attributed to specific concentrations (or a range of concentrations) of hydrogen sulfide. Table 1 also includes health effects of exposure to known concentrations of H_2S that were self-reported by participants in the studies discussed below.

[41] Knight, 2005. p.183.
[42] Snyder, Jack W., MD, PhD. et al.. "Occupational Fatality and Persistent Neurological Sequelae After Mass Exposure to Hydrogen Sulfide." *American Journal of Emergency Medicine*. **13**: (2) 199-203. 1995. p.201.

Table 1: Health Effects Associated with Hydrogen Sulfide[43]

Concentration (ppm)	Length of exposure	Effect	Source
0.0057	*Community/chronic*	*Eye and nasal symptoms, coughs, headaches and/or migraines*	*Partti-Pellinen, p.316.*
0.003 – 0.02	Immediate	Detectable odor	EPA Report 1993, p.III-5
0.01	*Community/chronic*	*Neurophysiological abnormalities*	*Legator, p.124.*
0.1 – 1	*Not reported (n.r.)*	*Abnormal balance with closed eyes, delayed verbal recall, impaired color discrimination, decreased grip strength*	*Kilburn, 1999, p.210.*
0.2	n.r.	Detectable odor	Fuller, p.940
0.250 – 0.300	Prolonged	Nuisance due to odor from prolonged exposure	Milby, p.194
1 – 5	*n.r.*	*Abnormal balance with open and closed eyes, delayed verbal recall, impaired color discrimination, decreased grip strength, abnormal simple and choice reaction time, abnormal digit symbol and trailmaking.*	*Kilburn, 1999, p.210*
2 – 8	*Community*	*Malaise, irritability, headaches, insomnia, nausea, throat irritation, shortness of breath, eye irritation, diarrhea, and weight loss*	*EPA Report 1993, p. III-32.*
10	10 minutes	Eye irritation, chemical changes in blood and muscle tissue after 10 minutes	New York State Department of rt
> 30	Prolonged	Fatigue, paralysis of olfaction from prolonged exposure	Snyder, p.200
50	n.r.	Eye and respiratory irritation	Fuller, p.940
50 – 100	Prolonged	Prolonged exposure leads to eye irritation; eye irritation (painful conjunctivitis, sensitivity to light, tearing, clouding of vision) and serious eye injury (permanent scarring of the cornea)	Milby p.194; EPA Report 1993,
150 – 200	n.r.	Olfactory nerve paralysis	EPA Report 1993, p.III-6
200	n.r.	Respiratory and other mucous membrane irritation	Snyder, p.200
250	n.r.	Damage to organs and nervous system; depression of cellular metabolism	EPA Report 1993, p.III-5
250	Prolonged	Possible pulmonary edema from prolonged exposure	Milby p.193
320 – 530	n.r.	Pulmonary edema with risk of death	Kilburn (1999), p.212
500	30 minutes	systemic symptoms after 30 minutes	Fuller, p.940
500 –1000	Immediate	Stimulation of respiratory system, leading to hyperpnoea (rapid breathing); followed by apnea (cessation of breathing)	EPA Report 1993, p.III-5
750	Immediate	Unconsciousness, death	Fuller, p.940
1000	Immediate	Collapse, respiratory paralysis, followed by death	Fuller, p.940, EPA Report 1993 p.
750 – 1000	Immediate	Abrupt physical collapse, with possibility of recovery if exposure is terminated; if not terminated, fatal respiratory paralysis	Milby, p.192
1000 – 2000	n.r.	Immediate collapse with paralysis of respiration	Kilburn (1999), p.212
5000	Immediate	Death	Fuller, p.940

[43] Italics signify concentrations and health effects in studies that rely on self-reporting of symptoms, usually in questionnaires.

5.1 Literature Review - Acute Exposure

The following studies focused on short-term exposure to relatively high levels of hydrogen sulfide, the kind of scenario that can be expected from an accidental release. There are many documented instances and peer-reviewed studies of serious health effects and deaths from exposure to relatively high concentrations of hydrogen sulfide.

Fuller and Suruda (2000), who reviewed Occupational Safety and Health Administration (OSHA) investigation records from 1984 to 1994, reported 80 deaths in the United States from occupational exposure to hydrogen sulfide, out of a total 18559 occupational death during this period.[44] Twenty-two of the 80 deaths were in the oil and gas industry.[45] These deaths occurred as a result of workers' exposure to accidental releases of hydrogen sulfide in high concentrations. The authors concluded that portable H_2S meters or alarms could have prevented these deaths.[46]

In their 1997 study, Hessel et al. submitted a questionnaire about health effects from hydrogen sulfide exposure to 175 oil and gas workers in Alberta, Canada, a known region of sour gas. Of the 175 workers, one third reported having been exposed to H_2S, and 14 workers (8%) experienced knockdown,[47] a term for the loss of consciousness due to inhaling high concentrations of hydrogen sulfide. The workers who had experienced knockdown exhibited the respiratory symptoms of shortness of breath, wheezing while hurrying or walking up hill, and random wheezing attacks.[48] The investigators found no

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[44] Fuller, Douglas C., MD, MPH, and Anthony J. Suruda, MD, MPH. "Occupationally Related Hydrogen Sulfide Deaths in the United States From 1984 to 1994." *Journal of Occupational and Environmental Medicine*. **42**:(9) 939-942. September 2000. p.940.
[45] Fuller and Suruda, p.941.
[46] Fuller and Suruda, p.942.
[47] Hessel, Patrick A., PhD. et al.. "Lung Health in Relation to Hydrogen Sulfide Exposure in Oil and Gas Workers in Alberta, Canada." *American Journal of Industrial Medicine*. **31**:554-557. 1997., p.555
[48] Hessel, pp.555-556.

"measurable pulmonary health effects as a result of exposure to H_2S that were intense enough to cause symptoms but not intense enough to cause unconsciousness."[49] In other words, the workers who reported initially experiencing symptoms from H_2S exposure did not report exhibiting any lingering respiratory symptoms at the time of the study. However, other kinds of long term effects could exist; indeed, the study itself acknowledged that long term effects of acute short term exposure have not been studied enough, and finds this lack "noteworthy."[50]

Milby and Baselt (1999) relied on a review of literature about hydrogen sulfide poisoning, and state that "A phenomenon referred to as 'knockdown' has been reported in oil field workers and others to describe sudden, brief loss of consciousness followed by immediate full recovery after short-lived exposure to very high concentrations of hydrogen sulfide (e.g., 750-1000 ppm)."[51] However, other studies have contested this claim of full recovery following a knockdown.

Kaye Kilburn, a medical doctor and professor of medicine at the University of Southern California, has devoted a considerable part of his career to studying and reporting on the adverse health effects of hydrogen sulfide. Refuting Milby and Baselt's (1999) finding that full recovery followed unconsciousness, or 'knockdown,' Kilburn states, "In 1989, for the first time, sensitive testing showed that, although survivors who had been unconscious looked all right, brain functions were impaired. Similar impairments were measured in people exposed to amounts below 50 ppm that had not caused unconsciousness. Next, subtle impairments of brain function were measured from

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[49] Hessel, p..556.
[50] Hessel, p.555.
[51] Milby, Thomas H. MD, and Randall C. Baselt, PhD. "Hydrogen Sulfide Poisoning: Clarification of Some Controversial Issues." *American Journal of Industrial Medicine*. **35**: 192-195. 1999. p.192.

exposures to concentrations of less than 5 ppm in air."[52] Kilburn reported examining one oil field worker, Stan, who had experienced 'knockdown' on the job after exposure to 1 percent hydrogen sulfide concentration (or 9,999 ppm as Stan's meter recorded it.) Three years after the incident, while appearing physically healthy, Kilburn's tests of Stan revealed significant brain damage (IQ lowered to 77, though the previous IQ is not reported), severely impaired balance and motor function, and inability to recall stories and visual designs.[53]

Another study by Kilburn (2003)[54] reported long term effects of hydrogen sulfide exposure. Kilburn performed physiologic and psychological measurements on nineteen exposed and 202 unexposed subjects.[55] Ten of the nineteen subjects were exposed at work, including four at oil and gas sites, while the other nine were exposed in their residences, which were near various sources of H_2S.[56] The concentrations to which the subjects were exposed are not known. Exposure times ranged from twenty minutes to nine years, and Kilburn examined the subjects from 1.7 to 22 years after their exposures.[57] The study methods consisted of a questionnaire and a series of neurophysiological and neuropsychological tests. The neurophysiological tests measured simple reaction time, visual two-choice reaction time, balance, color recognition, and hearing, and the neuropsychological tests measured immediate memory recall, mood, and vocabulary.[58] Tension, depression, anger, fatigue, and confusion were all significantly elevated in the

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[52] Kaye H. Kilburn. "Killer Molecules in Natural Gas." Chapter 7 in *Endangered Brains: How Chemicals Threaten Our Future*. Birmingham, AL: Princeton Scientific Publishers Company, Inc. 2004. p.78.
[53] Kilburn, (2004) p.79.
[54] Kilburn, Kaye H. "Effects of Hydrogen Sulfide on Neurobehavioral Function." *Southern Medical Journal*. **96**: (7) 639-646. 2003.
[55] Kilburn, (2003), p.640.
[56] Kilburn, (2003), p.640, see Table 1, p.641.
[57] Kilburn, (2003), p.640.
[58] Kilburn, (2003), pp.640-641.

exposed subjects compared to the control group. In addition, respiratory symptoms were more prevalent among the exposed subjects.[59] Even subjects who did not experience unconsciousness at the time of their exposure exhibited permanent neurobehavioral damage.[60]

The studies mentioned thus far focused on occupational exposure. They document the dangerous properties of hydrogen sulfide, as well as highlight the fact that more research is needed on the long term effects of even short duration exposures. There have been some studies of non-occupational exposure to relatively high H_2S levels. The proximity of oil refineries, gas treatment and processing plants, and oil and gas wells to residences constitutes a likely source of H_2S emissions and potentially poses a risk to people in a non-occupational setting.

Kilburn has studied the health effects of a series of explosions at an oil refinery in Wilmington, California, which occurred in October 1992. The explosions released unknown amounts of hydrogen sulfide into the air, making people ill in Wilmington, Torrance, Carson, Long Beach, and South Los Angeles.[61] Some street monitors recorded H_2S concentrations as high as 24 ppm, and since no one died, Kilburn concluded that concentrations probably did not exceed 200 ppm. Seven thousand people who had been exposed and sickened filed a consolidated lawsuit against the refinery, and a random sample were examined three and a half years after the explosion for court proceedings.[62]

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[59] Kilburn, (2003), p.643.
[60] Kilburn, (2003), p.644.
[61] Kilburn, (2004) p.77.
[62] 400 people were selected to represent the 7000 filing suit, and 120 were selected at random to be examined by a general practitioner. Then, 68 of the 120 were examined using sensitive neurobehavioral tests. Kilburn, (2004) p.81.

Persistent symptoms included impaired balance, delayed recall memory, elevated depression and confusion scores, and abnormally slow reaction times.[63]

As background to their 1987 study, which focused on methods of improving the prediction and management of public health risks associated with the development of sour gas wells, Layton and Cederwall[64] summarized studies of two incidents during which people were exposed to hydrogen sulfide released from gas operations. One occurred in 1950 in Poza Rica, Mexico, where 320 people were hospitalized and 22 died as a result of a major hydrogen sulfide release from a gas purification plant.[65] The second incident, known as the Lodgepole blowout, was a sour gas blowout in Alberta, Canada, in 1982. In this case, the hydrogen sulfide releases lasted for 67 days, and the affected people reported headaches, eye irritation, and various respiratory and gastrointestinal symptoms.[66] In both instances, there were no reliable measurements of H_2S concentrations. In Alberta, maximum reported hourly concentrations were 15 ppm, and concentrations 100 kilometers away from the source were below 100 ppb, but residents there filed over a thousand complaints.[67] This study concluded that the hazard zone for sublethal effects around sour gas wells encompasses from less than 400 meters up to 6500 meters, while lethal exposure to hydrogen sulfide could occur as far as 2000 meters from the source.[68] Among the proposed recommendations for improving public safety is "preemptive land ownership,"[69] an issue which I revisit in the Concluding Remarks section. This study also stressed that

[63] Kilburn, (2004) p.81.
[64] Layton, David W. and Richard T. Cederwall. 1987. "Predicting and Managing the Health Risks of Sour-Gas Wells." *Journal of the Air Pollution Control Association.* **37**: 1185-1190.
[65] Layton and Cederwall, 1987. pp.1185-1186.
[66] Layton and Cederwall, 1987. p 1186.
[67] Layton and Cederwall, 1987. p 1186.
[68] Layton and Cederwall, 1987. p 1188.
[69] Layton and Cederwall, 1987. p 1187.

sublethal effects of hydrogen sulfide are not well studied and that the dose-response relationship at lower levels is not well characterized.[70]

5.2 Literature Review - Chronic Exposure

Literature is also available on the human health impacts of chronic exposure to relatively low concentrations of hydrogen sulfide. Generally, chronic exposure to low-level concentrations of hydrogen sulfide is associated with neurological symptoms that include fatigue, loss of appetite, irritability, impaired memory, altered moods, headaches, and dizziness.[71] At persistent concentrations of 0.250 to 0.300 ppm (250 to 300 ppb), the rotten egg odor of H_2S creates a nuisance to communities, and exposure to such concentrations has been documented to affect quality of life by causing headaches, nausea, and sleep disturbances.[72]

Schiffman et al. (1995) evaluated the effect of odors emanating from swine operations on mood.[73] Although the source of odors were swine operations rather than oil and gas sites, the study is relevant because hydrogen sulfide caused the persistent odors, much as is the case near oil refineries and natural gas processing plants. This study concluded that continuously smelling odors is associated with "significantly more tension, more depression, less vigor, more fatigue, and more confusion."[74]

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[70] Layton and Cederwall, 1987. p 1185.
[71] McGavran, Pat. "Literature Review of the Health Effects Associated with the Inhalation of Hydrogen Sulfide." Idaho Department of Environmental Quality, Boise, Idaho. June 19, 2001. p.3.
[72] Milby, 1999, p.194.
[73] Schiffman, Susan S., Elizabeth A. Sattely, et al.. "The Effect of Environmental Odors Emanating From Commercial Swine Operations on the Mood of Nearby Residents." *Brain Research Bulletin*. 37:4 369-375. 1995
[74] Schiffman et al., p.371.

One frequently cited study, by Partti-Pellinen et al. (1996), examined the health effects of chronic, low-level exposure to sulfur compounds, including hydrogen sulfide, near a paper and pulp mill in Finland.[75] They found that the exposed people experienced eye and nasal symptoms, coughs, and headaches or migraines much more frequently than the people in the control group, while acute respiratory infections also occurred more frequently in the study group.[76] Once again, the study acknowledged the lack of data on long term effects of low-dose, chronic exposure, and concluded that, at the very least, the exposure and odor make "everyday life uncomfortable."[77]

Legator et al. (2001) investigated the effects of chronic, low levels of hydrogen sulfide by surveying two exposed communities, Odessa, Texas, and Puna, Hawaii, and comparing the health findings with several control communities.[78] Due to emissions from industrial wastewater, ambient concentrations of H_2S in Odessa, Texas, registered at 335 to 503 ppb over 8 hours, 101 to 201 ppb over 24 hours, with an annual average of 7 to 27 ppb.[79] Puna, Hawaii, is situated in a volcanically active area.[80] There were no reliable measurements of H_2S levels at Puna—they ranged from less than 1 ppb to periodic highs of 200 to 500 ppb. The study relied on a multi-symptom health survey and found various adverse health effects associated with hydrogen sulfide exposure in the study populations. The health symptoms included central nervous system impacts (fatigue, restlessness,

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[75] Partti-Pellinen, Kirsi, Marttila Olli, Vilkka Vesa, et al.. "The South Karelia Air Pollution Study: effects of low-level exposure to malodorous sulfur compounds on symptoms." *Archives of Environmental Health.* **51**. (4) 315-320 1996. The study looked at the main components of total reduced sulfur (TRS) compounds—hydrogen sulfide H_2S, methyl mercaptan, CH_3SH, dimethyl sulfide $[CH_3]_2S$, and dimethyl disulfide $[CH_3]_2S_2$.

[76] Partti-Pellinen et al.. Acute respiratory infections occurred 1.6 times per year in the study group as compared to 1.1 times per year in the control group.

[77] Partti-Pellinen, et al., p.320.

[78] Legator, Marvin S., et al.. "Health Effects from Chronic Low-Level Exposure to Hydrogen Sulfide." *Archives of Environmental Health*. **56:** (2) 123-131. March/April 2001.

[79] Legator, p.124.

[80] Since 1976, Puna is a site of geothermal energy production, and supplies about 30% of Hawaii's electricity. US Department of Energy.

depression, short term memory loss, balance, sleep problems, anxiety, lethargy, headaches, dizziness, tremors), respiratory system impacts (wheezing, shortness of breath, coughing), and various ear, nose, and throat symptoms.[81] This study also concluded with a call for more research:

> The findings in our study, taken together with previously reported data concerning adverse responses to H_2S, strongly mandate the need for continued research on the possible detrimental effects of chronic exposure to the toxic agent. This is of decided public health significance, given the relatively large segment of the population that is regularly exposed to low levels of H_2S.[82]

Kilburn has also studied health impacts from chronic exposure to lower concentrations of hydrogen sulfide. He examined a preacher and eighteen congregation members in Odessa, Texas, who lived downwind from an oil refinery and often smelled the characteristic rotten egg odor of H_2S, occasionally experiencing nausea and vomiting.[83] Kilburn observed impaired balance, delayed verbal recall for stories, and difficulty distinguishing colors among the people he studied in Odessa.[84] Workers and people living downwind of another oil refinery, in Nipoma Mesa near San Luis Obispo, California, also exhibited impaired reaction time, impaired balance, depression, and impaired recall memory.[85]

As a result of poorly plugged wells of an abandoned oil and gas field in Long Beach, California, people living in a community built on this location were exposed to hydrogen sulfide that collected under concrete foundations and crawl spaces of homes,

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[81] Legator, pp.126-129.
[82] Legator, p.130.
[83] Kilburn, (2004) p.79.
[84] Kilburn, (2004) p.80.
[85] Kilburn, (2004) p.80.

and in a low lying area around a communal swimming pool.[86] The H_2S measurements ranged from 0.1 ppm to 1 ppm, with several peaks up to 5 ppm.[87] Kilburn examined 24 people from this community, and recorded abnormal balance with closed eyes, delayed verbal recall, and impaired color discrimination and grip strength, as compared to a control group.[88]

As reported by the EPA,[89] two notable occasions of increased ambient concentrations of hydrogen sulfide occurred in Great Kanawha River Valley, West Virginia, in 1950, and in Terre Haute, Indiana, in 1964. In Terre Haute, ambient H_2S concentrations ranged from 2 to 8 ppm, emanating from a lagoon. In West Virginia, the highest concentration was 293 ppb, but there is no information on other levels. In both cases, symptoms included malaise, irritability, headaches, insomnia, and nausea, while the people exposed in Terre Haute also reported, among other effects, throat irritation, shortness of breath, eye irritation, diarrhea, and weight loss.[90] These incidents provide some evidence of health impacts from chronic exposure to ambient levels of hydrogen sulfide in the range that may be expected to occur near oil and gas sites.

Tarver and Dasgupta (1997) measured hydrogen sulfide concentrations near several oil fields in western Texas.[91] Although the researchers were studying the effects of increased anthropogenic sources of sulfur emissions on the sulfur cycle, the authors nevertheless gathered data that is pertinent to my research. The study found nighttime

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[86] Kilburn, Kaye H. "Evaluating health effects from exposure to hydrogen sulfide: central nervous system dysfunction." *Environmental Epidemiology and Toxicology*. **1**:207-216. 1999. p.208.
[87] Kilburn (1999), p.208.
[88] Kilburn, (1999), p.210.
[89] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-32. For the entire paragraph.
[90] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-32
[91] Tarver, Gary A. and Purnendu K. Dasgupta. "Oil Field Hydrogen Sulfide in Texas: Emission Estimates and Fate." *Environmental Science and Technology*. **31**: (12) 3669-3676. 1997.

maximum H_2S concentrations between 1 and 5 ppb.[92] While this concentration of hydrogen sulfide is only enough to produce an odor, a persistent odor can be a nuisance, and has been associated with increased tension, depression, fatigue, confusion, and decreased vigor.[93]

Some evidence exists on the effects of hydrogen sulfide on the reproductive system. Xu et al. (1998) conducted a retrospective epidemiological study to assess the association between spontaneous abortion and exposure to petrochemicals.[94] By reviewing the plant employment records, which also contain medical information, the researchers identified over 3000 women from the Beijing Yanshan Petrochemical Corporation who had been pregnant. Trained interviewers administered a questionnaire to gather information on the subjects' reproductive history, pregnancy outcomes, employment history, occupational exposure, smoking habits, alcohol consumption, indoor air pollution, diet, and demographic variables.[95] The study found that "exposure to petrochemicals, specifically benzene, gasoline, and hydrogen sulphide is significantly associated with increased frequency of spontaneous abortion."[96] Each chemical was individually found to have a statistically significant effect on the frequency of spontaneous abortion. Although the exposures mainly occurred in maintenance operations or due to accidental leaks and spillages,[97] rather than being chronic low level exposures,[98] this study is nevertheless important for the link it established between hydrogen sulfide

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[92] Tarver and Dasgupta, p.3673.
[93] Schiffman et al. Discussed above on p.18.
[94] Xu, Xiping, Sung-Il Cho, et al.. "Association of petrochemical exposure with spontaneous abortion." *Occupational and Environmental Medicine*. 55: 31-36. 1998.
[95] Xu et al., p.31.
[96] Xu et al., p.34.
[97] Xu et al., p.35.
[98] The study acknowledged that "at lower exposures, the reproductive effects of hydrogen sulphide have not been determined, although it has been shown to enhance the fetal toxicity of carbon disulphide." Xu et al., pp.34-35.

and effects on the reproductive system. According to one personal account recounted below, hydrogen sulfide exposure is associated with spontaneous abortions in cattle as well as other reproductive effects in animals.

Most studies acknowledge that there is a need for more research on the health impacts of chronic exposure to lower concentrations of H_2S. Although the health effects are not well documented,[99] many studies recognize the potential for harm. In 1993, the EPA prepared an in-depth report on hydrogen sulfide emissions associated with oil and gas extraction.[100] The report matched available routine emissions data from oil and gas sites with studies documenting health effects of these levels, and assessed the risk of accidental releases, to determine whether these warrant a national control strategy.[101] Although the report acknowledged that oil refineries and gas processing plants are a major possible source of H_2S, these were not included in the analysis because they fall outside the definition of the term 'extraction.'[102] The report also excluded exploration and well development activities. Each of these areas of oil and gas operations is a potential source of hydrogen sulfide emissions.

The report concluded that "the potential for human and environmental exposures from routine emissions of H_2S from oil and gas wells exists, but insufficient evidence exists to suggest that these exposures present any significant threat,"[103] and that "there appears to be no evidence that a significant threat to public health or the environment exists from routine H_2S emissions from oil and gas extraction."[104] The EPA reached this

[99] New York State Department of Health, http://www.health.state.ny.us/nysdoh/environ/btsa/sulfide.htm
[100] EPA, "Report to Congress on Hydrogen Sulfide Emissions."
[101] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-1.
[102] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.I-4.
[103] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.iii.
[104] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.V-1.

conclusion "from the limited data available."[105] However, because, as the report itself acknowledged, there is not enough information on ambient air quality around well sites,[106] the conclusion that there are no health risks is ill founded. A call for further research would have been more appropriate, but strikingly, the "Research and Further Studies" section of the last chapter does not recommend additional research of routine hydrogen sulfide emissions and health effects.

[105] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.V-1.
[106] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-1.

Table 2: Summary of Studies

	Author(s) / Date	Discipline	Motivation for Study / Summary of Findings
Acute Exposure	Fuller and Suruda (2000)	Medicine	To determine the number of occupational deaths related to hydrogen sulfide; review of OSHA records; acute exposure
	Milby and Baselt (1999)	Medicine / Toxicology	Review of literature on hydrogen sulfide; focusing on neurotoxic effects of acute exposure, effects on the lungs, diagnosis of poisoning, and community exposure issues.
	Hessel et al. (1997)	Public Health	To assess pulmonary health effects of oil and gas workers in Alberta, Canada; administered questionnaire to 175 workers
	Snyder et al. (1995)	Medicine	To assess neurological problems from exposure to hydrogen sulfide; review of case reports from an incident of mass exposure to H2S in New Jersey; calls for annual neurological and neuropsychological testing of exposed subjects to enhance knowledge of long term effects
Chronic Exposure	Parti-Pellinen et al. (1996)	Medicine / Public Health	Examined health effects chronic, low-level exposure to sulfur compounds, including H2S, near a paper and pulp mill; administered cross-sectional questionnaire to 336 subjects and to a reference community; increased frequency of eye and nasal symptoms, coughs, and headaches or migraines, and acute respiratory infections.
	Legator et al. (2001)	Medicine / Toxicology / Public Health	Investigate effects of chronic exposure to low levels of hydrogen sulfide; multi-symptom health survey submitted to two exposed communities – Odessa, Texas and Puna, Hawaii, and to control communities; found central nervous system impacts: fatigue, restlessness, depression, short term memory loss, balance and sleep problems, anxiety, lethargy, headaches, dizziness, tremors; respiratory system impacts: wheezing, shortness of breath, coughing; and various ear, nose, and throat symptoms.
	Tarver and Dasgupta (1997)	Chemistry	To determine hydrogen sulfide concentrations near oil fields in Western Texas
	Xu et al. (1998)	Medicine / Epidemiology	To determine effects of exposure to hydrogen sulfide on the reproductive system; conducted a retrospective epidemiological study to assess the association between spontaneous abortion and exposure to petrochemicals in Beijing, China; found an association.
	Kilburn (1999)	Epidemiology	To determine long-term effects of exposure to hydrogen sulfide; examined and submitted a questionnaire to four groups of people that were exposed to hydrogen sulfide (from boreholes in the ground, downwind of a refinery, due to an oil refinery explosion, and a group of people exposed to odors); found abnormal balance, delayed verbal recall, impaired color discrimination and grip strength.
	Schiffman et al. (1995)	Psychiatry	To determine the effect of persistent environmental odors on the mood of people living near the source of odors; submitted a questionnaire to 44 subjects and 44 controls; found more tension, depression, fatigue, and confusion, and less vigor among the exposed subjects.
	Kilburn (2003)	Epidemiology	To measure long term effects of hydrogen sulfide exposure – various lengths of exposure and various concentrations; submitted a questionnaire, and performed neuropsychological and neurophysiological tests on 19 exposed subjects and 202 unexposed subjects; found elevated tensions, depression, anger, fatigue, and confusion, and more prevalent respiratory symptoms among exposed subjects.
Other	Layton and Cederwall (1987)	Engineering / Public Health	Methods for improving the prediction and management of public health risks associated with development of sour gas wells
	Knight and Presnell (2005)	Medicine / pathology	Review of literature on H2S toxicology; case study of two fatalities due to occupational exposure to H2S

6. Regulations and Recommendations for Exposure to Hydrogen Sulfide

6.1 Federal Recommendations and Regulations

At the federal level, some regulations and recommendations exist to protect humans from the health effects of exposure to hydrogen sulfide. Regulations are laws that can be enforced by agencies such as the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and the Occupational Safety and Health Administration (OSHA). Recommendations, on the other hand, do not carry the force of law, and are determined by agencies such as the National Institute for Occupational Safety and Health (NIOSH) and the Agency for Toxic Substances and Disease Registry (ATSDR), both part of the federal Centers for Disease Control and Prevention (CDC).

The American Conference of Governmental Industrial Hygienists (ACGIH), a longstanding member-based organization committed to promoting worker health and safety, also recommends exposure limits for various substances. The current ACGIH hydrogen sulfide standards are 10 ppm for the Threshold-Limit Value-Time Weighted Average (TLV-TWA), and 15 ppm for the TLV short term exposure limit (TLV-STEL). The TVL-TWA is the time-weighted average concentration to which workers can be routinely and consistently exposed over an 8-hour workday and 40-hour workweek without adverse effect. The TVL-STEL is the concentration to which workers can be exposed for short periods of time without suffering adverse health effects. The ACGIH updates its standards annually, and can relatively quickly modify its standards in response to new research.[107]

[107] EPA "Report to Congress on Hydrogen Sulfide Emissions," p.III-10.

OSHA began setting standards for workers' exposure to hazardous substances in the 1970s, and initially adopted the ACGIH values.[108] The current OSHA workplace standard for H_2S exposure is 10 parts per million (ppm), while the exposure times are longer than the ACGIH recommends. In more detail, according to OSHA, "Exposures shall not exceed 20 ppm (ceiling) with the following exception: if no other measurable exposure occurs during the 8-hour work shift, exposures may exceed 20 ppm, but not more than 50 ppm (peak), for a single time period up to 10 minutes."[109] The OSHA regulations do not specify an 8-hour time weighted average (TWA) for H_2S. Exposure to these concentrations even for the seemingly short duration of 10 minutes can nevertheless result in eye and respiratory irritation, according to several sources. The NIOSH recommended exposure limit to the OSHA 10 ppm standard is 10 minutes, and its Immediately Dangerous to Life or Health (IDLH) H_2S concentration is 100 ppm.[110] OSHA standards have the force of law, while ACGIH's and NIOSH's levels are only recommendations.

It is important to note that OSHA standards apply only to workplaces and not to domestic situations or residences. The human data on which the standards are based are from uncontrolled exposure incidents, so the levels of exposure are crudely estimated.[111] In general, the controlled exposure data is derived from animal studies and then extrapolated to humans. As one study discussed above summed up, "a precise ratio with which to predict human effects on the basis of the ratio of rat-to-human effects is

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[108] EPA "Report to Congress on Hydrogen Sulfide Emissions," p.III-10.
[109] Occupational Safety and Health Administration, 29 CFR 1910.1000, available at http://www.osha.gov/dts/chemicalsampling/data/CH_246800.html
[110] NIOSH is a department within the Centers for Disease Control and Prevention. See http://www.cdc.gov/niosh/npg/npgd0337.html for NIOSH's H_2S exposure recommendations.
[111] Guidotti, Tee L. 1994. "Occupational exposure to hydrogen sulfide in the sour gas industry: some unresolved issues." *International Archives of Occupational and Environmental Health*. p.157.

lacking."[112] Further, the standards are based on the expected effects of hydrogen sulfide on healthy adult males, so people who are young, old, or have compromised immune systems may be at risk at considerably lower concentrations of H_2S. Additionally, exposure to hydrogen sulfide may affect the human reproductive system, as determined in the study by Xu et al. and reported above, so standards based on males may not protect women's reproductive health.

In addition to general standards for workplace inhalation exposure, OSHA specifically sets standards for industries in which hydrogen sulfide occurs in quantities exceeding 1500 pounds, in their Process Safety Management of Highly Hazardous Chemicals Standard (1910-119). Significantly, the oil and gas industry is exempt from this standard.[113] According to the 1993 EPA report, the reason OSHA gave for this exemption is that OSHA "continues to believe that oil and gas well drilling and servicing operations should be covered in a standard designed to address the uniqueness of the industry."[114] OSHA also proposed a monitoring program for hydrogen sulfide for drilling and service operations that occur in areas where H_2S exposure is a potential risk.[115] Neither of these exists at the time of writing.

The 1990 Clean Air Act is the primary federal law that regulates air pollution. The EPA sets the levels of various air pollutants, including the National Ambient Air Quality Standards (NAAQS) for six criteria pollutants and the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for another 188 substances commonly referred to as

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[112] Kilburn, Kaye H. "Effects of Hydrogen Sulfide on Neurobehavioral Function." 2003. p.639.
[113] OSHA, http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760
[114] As quoted in EPA "Report to Congress on Hydrogen Sulfide Emissions," p.IV-28.
[115] EPA "Report to Congress on Hydrogen Sulfide Emissions," p.IV-30.

HAPs.[116] The EPA does not regulate hydrogen sulfide as one of its criteria pollutants nor as one of the HAPs under the 1990 Clean Air Act. When George Bush, Sr. signed the Clean Air Act in 1990, H_2S was not among the 188 chemicals on the final HAPs list to be regulated, despite the calls of public interest groups and government scientists, some even within the EPA, for its inclusion. Hydrogen sulfide had been on the proposed original list of hazardous substances,[117] and was removed from this list as a result of successful efforts by the oil and gas, chemical, and paper industries.[118] For instance, the American Petroleum Institute, representing the interests of the oil and gas industry, argued that H_2S emissions are an "accidental-release issue" rather than a routine one,[119] and that H_2S therefore should not be regulated as one of the Clean Air Act's Hazardous Air Pollutants. This lack of an EPA standard has prompted one newspaper to label hydrogen sulfide "the least regulated common poison."[120]

Hydrogen sulfide is on the EPA's list of Extremely Hazardous Substances,[121] another category under the Clean Air Act, which regulates substances "known or may be anticipated to cause death, injury, or serious adverse effects to human health or the

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[116] According to the EPA, "Hazardous air pollutants, also known as toxic air pollutants or air toxics, are those pollutants that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects." http://www.epa.gov/ttn/atw/pollsour.html

[116] Interestingly, hydrogen sulfide remained on the list as a result of "administrative error" until it was removed by a Senate Joint Resolution on August 1, 1991. See http://www.epa.gov/ttn/atw/pollutants/atwsmod.html for details.

[117] Interestingly, hydrogen sulfide remained on the list as a result of "administrative error" until it was removed by a Senate Joint Resolution on August 1, 1991. See http://www.epa.gov/ttn/atw/pollutants/atwsmod.html for details.

[118] Jim Morris. "Lost Opportunity: EPA had its chance to regulate hydrogen sulfide." November 8, 1997. *The Houston Chronicle.*

[119] As quoted in *The Houston Chronicle.*

[120] Jim Morris, *The Houston Chronicle.*

[121] Environmental Protection Agency, Chemical Emergency Preparedness and Prevention. Look for H_2S on the list at http://yosemite.epa.gov/oswer/ceppoehs.nsf/Alphabetical_Results!OpenView&Start=146

environment upon accidental release."[122] This classification requires companies that produce the substance to develop plans to prevent and respond to accidental releases. Importantly, however, this classification does not require regular emission controls of the substance.[123] Additionally, H_2S is not on the list of toxic substances whose releases companies are required to report under the EPA's Toxic Release Inventory (TRI).[124] This exclusion is due to an administrative stay put in place on August 22, 1994, as a result of lobbying by a paper, forest, and wood products industry association.[125] The administrative stay will remain in effect until the EPA decides to lift it.

At the time of writing, the EPA is considering whether to re-evaluate including hydrogen sulfide on the HAPs list of the Clean Air Act.[126] The EPA is motivated by some concerns regarding chronic and acute exposure to hydrogen sulfide.[127] Further, if they proceed with research, the EPA's findings may inform action on the current administrative stay that is responsible for exempting H_2S from TRI reporting requirements.[128]

The EPA does, however, have an inhalation reference concentration (RfC) for hydrogen sulfide, which is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a

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[122] Section 112(r) of the Clean Air Act, as cited in EPA, "Report to Congress on Hydrogen Sulfide Air Emissions," p.i.
[123] Jim Morris, *The Houston Chronicle*.
[124] EPA's Toxic Release Inventory list of chemicals for Reporting Year 2004. Available at http://www.epa.gov/tri/chemical/RY2004ChemicalLists.pdf
[125] See http://www.epa.gov/tri/guide_docs/2001/brochure2000.pdf, footnote on p.18.
[126] Personal communication with Jim Hirtz, February 24, 2006. US EPA, Health and Environmental Impacts Division, Research Triangle, North Carolina. The EPA undertook this action in response to a request by an environmental organization from Texas.
[127] Personal communication with Jim Hirtz, February 24, 2006. US EPA, Health and Environmental Impacts Division, Research Triangle, North Carolina.
[128] Personal communication with Jim Hirtz, March 2, 2006. US EPA, Health and Environmental Impacts Division, Research Triangle, North Carolina.

lifetime."[129] The RfC is one important standard for chronic exposure. According to the EPA's on-line Integrated Risk Information System (IRIS) database, the current inhalation RfC for hydrogen sulfide is $2x10^{-3}$ mg/m^3 (1.4 ppb). Applying the RfC definition, this means that it is possible that inhaling more than this concentration on a daily basis over a lifetime poses "an appreciable risk of deleterious effects." The RfC is well below any occupational standards set by OSHA or recommended by NIOSH and the ACGIH

The EPA also recommends levels of hydrogen sulfide for their Acute Exposure Guideline Levels (AEGL) for various exposure periods. These threshold exposure limits apply to the general public for emergency exposures ranging from 10 minutes to 8 hours, and are "intended to describe the risk to humans resulting from once-in-a-lifetime, or rare, exposure to airborne chemicals."[130] Appendix A includes definitions of the AEGL categories, and the recommended H_2S levels for each exposure period and AEGL category.

Other guidelines also exist for exposure to hydrogen sulfide in emergency situations. To protect the health of the general public in the event of an emergency release, the American Industrial Hygiene Association (AIHA) establishes Emergency Response Planning Guidelines (ERPGs), which specify one-hour exposure limits. These limits are also included in the table in Appendix A.

The National Research Council's Committee on Toxicology recommended Emergency Exposure Guidance Level (EEGL) to the Department of Defense for

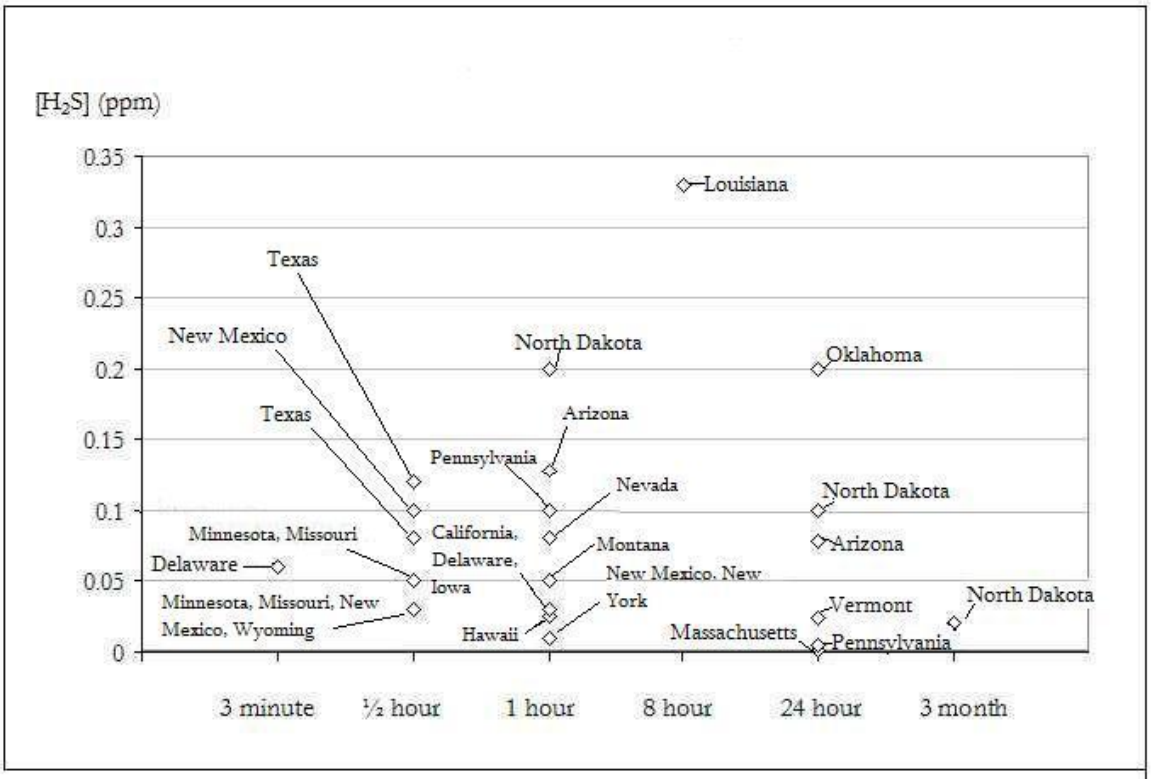
[129] EPA Integrated Risk Information System, Hydrogen sulfide (CASRN 7783-06-4), http://www.epa.gov/iris/subst/0061.htm.
[130] EPA, The Development of Acute Exposure Guideline Levels (AEGLs), http://www.epa.gov/oppt/aegl/index.htm

maximum concentrations acceptable in rare situations such as spills and fires.[131] The EEGLs apply to young and healthy military personnel, and exist for 41 substances, of which hydrogen sulfide is one. The 10 minute EEGL for H_2S is 50 ppm, and the 24 hour H_2S EEGL is 10 ppm.[132]

6.2 State Regulations

In the absence of federal standards for ambient levels of hydrogen sulfide, twenty states have passed their own laws to regulate H_2S emissions. Figure 2 is a snapshot of state ambient hydrogen sulfide regulations. It illustrates the wide range of existing state standards.

Figure 2: State Ambient H_2S Regulations



[131] National Oceanic and Atmospheric Administration, Office of Response and Restoration, "Public Exposure Guidelines" at http://archive.orr.noaa.gov/cameo/locs/expguide.html
[132] As cited in the EPA "Report to Congress on Hydrogen Sulfide Emissions," p.III-14.

A detailed table listing the states with ambient H_2S standards can be found in Appendix B. States set their standards based on a variety of justifications, and if available, these are also listed in Appendix B. I compiled this data by reviewing information available on each state environmental department's website, and by speaking with appropriate staff. Some states have based their ambient standard for hydrogen sulfide on odor thresholds, while others have based their standard on health considerations, either adopting the EPA's RfC inhalation guideline, modifying the OSHA safety standard to apply to continuous exposure, or basing their standard on other health studies. The fact that these states have taken the initiative to regulate ambient H_2S indicates that there is concern for human health even at these relatively low levels.

Many states' health/environmental departments routinely receive odor complaints about hydrogen sulfide. Specifically, staff at agencies in Colorado, Idaho, Iowa, Kansas, Michigan, Montana, Nevada, New Mexico, Ohio, Oregon, Texas, and Wyoming reported receiving many H_2S odor complaints. In Kansas and Ohio, people have also complained about health effects from hydrogen sulfide. In Colorado, there have been some cattle deaths attributed to exposure to hydrogen sulfide, which had collected in low-lying areas.

In addition to inquiring about ambient hydrogen sulfide standards, I collected information about any monitoring of H_2S – routine or otherwise – that the state agency conducts. The most frequently cited reason for the lack of routine monitoring, even in states with ambient H_2S standards, are budget constraints. A number of people said that monitoring and more information in general would be desirable. Some states have conducted periodic, project-based monitoring of hydrogen sulfide. Studies of hydrogen sulfide emissions from Arkansas, Colorado, Louisiana, New Mexico, and North Dakota

are available. These studies are of varying quality and scope, but each sheds some light on the topic of hydrogen sulfide emissions and oil and gas operations.

6.2.1 Special H_2S Monitoring Studies

6.2.1.1 Arkansas

The Arkansas Department of Environmental Quality conducted two hydrogen sulfide monitoring studies in response to numerous health and welfare related concerns of Texarkana residents about emissions from gas processing plants in the area.[133] The first study, spanning 1995 to 1997, was a scoping study to determine whether hydrogen sulfide was indeed present in ambient air and to determine whether the facilities that were emitting H_2S were in compliance with their emissions permits. After this study established that H_2S was present in the air, a second, more rigorous study was conducted from March 1998 through March 1999. The state does not have an ambient hydrogen sulfide standard.

The monitoring data from the latter study has been reported to the EPA's Air Quality System (AQS) database. The AQS database contains measurements of air pollutants – criteria pollutants, hazardous air pollutants, and other monitored substances – and this data is publicly available.[134] The Arkansas Department of Environmental Quality itself did not provide any monitoring data or comments. Data from the AQS site[135] is available for two monitoring locations, which are classified as rural residential. At the first monitoring location, the mean concentrations for the monitoring periods from May to

[133] Pleasant Hills H_2S Study, obtained February 2006 by mail from Jay Justice, Senior Epidemiologist with the Arkansas DEQ.
[134] http://www.epa.gov/air/data/aqsdb.html
[135] http://oaspub.epa.gov/aqspub1/aqs_query.psite The code for hydrogen sulfide is 42402.

July 1998, and October to December 1998, were 2.4 ppb and 3.4 ppb, respectively, and the maximum hydrogen sulfide concentrations were 35 ppb and 24 ppb, respectively. The levels of H_2S recorded at the second monitoring location for which data is available on the AQS site were slightly higher than at the first. The mean concentration in December 1998 was 4 ppb, and in January 1999, 5.5 ppb. The maximum concentration recorded in those months were 55 ppb and 127 ppb, respectively. These levels of hydrogen sulfide, while not very high, are nevertheless higher than normal urban background levels of up to 0.33 ppb.[136] The levels measured in this study may be expected to produce a persistent odor, which has been shown in one study (Schiffman et al., 1995) to have a negative effect on the mood of nearby residents. Based on the literature reviewed above, there is little evidence of more serious health effects attributable to these levels of H_2S.

6.2.1.2 Colorado

In 1997, the Colorado Department of Public Health and Environment (CDPHE), Air Pollution Control Division, conducted a monitoring study of H_2S concentrations near several known sources, and of urban and rural background ambient levels.[137] The CDPHE initially considered monitoring at oil and gas sites because of the information in the 1993 EPA report on emissions of H_2S at points of oil and gas extraction. Ultimately, the Colorado study excluded oil and gas operations, because of assurances from the Colorado Oil and Gas Conservation Commission (COGCC) that elevated H_2S levels are not

[136] Agency for Toxic Substances and Disease Registry (ATSDR). 2004. Toxicological profile for hydrogen sulfide (*Draft for Public Comment*). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Chapter 2, p.1.
[137] "Hydrogen Sulfide Concentrations in Colorado; Results from a Screening Survey." Prepared by The Technical Services Program, Air Pollution Control Division, Colorado Department of Public Health and the Environment, 1997. Obtained February 2006 by mail from Ray Mohr, CDPHE.

common in deposits in Colorado.[138] However, interviews with people living near oil and gas sites in Colorado, presented below, suggest that hydrogen sulfide is present near these facilities. The COGCC itself has not conducted any monitoring of H_2S at oil and gas sites. Thus, the question of what concentrations of hydrogen sulfide are present near oil and gas operations in the state is still unanswered. Colorado does not have an ambient hydrogen sulfide standard.

6.2.1.3 Louisiana

The Louisiana Department of Environmental Quality, motivated by numerous odor complaints from nearby residents, monitored hydrogen sulfide and sulfur dioxide concentrations downwind of the Calumet Refinery in Shreveport.[139] The hourly average concentration for hydrogen sulfide, for the monitoring period from October 2002 to April 2005, was 2.56 ppb, with a maximum of 50.15 ppb and a median of 1.92 ppb.[140] These measurements correspond to the range of the monitoring data from Arkansas, and the same analysis of potential health effects applies.

6.2.1.4 New Mexico

In February 2002, the Air Quality Bureau of the New Mexico Environment Department monitored hydrogen sulfide levels to determine if ambient concentrations near certain facilities are in compliance with the state's ambient standards.[141] Air samples

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[138] "Hydrogen Sulfide Concentrations in Colorado," p.2.
[139] James M. Hazlett, "Report for the Calumet Air Monitoring Project," Louisiana Department of Environmental Quality, Office of Environmental Assessment. June 8, 2005. (obtained from the author and used with permission.)
[140] Hazlett, p.4.
[141] New Mexico Environment Department (NMED), Air Quality Bureau. "Trip Report: H_2S Survey, March 18-22, 2002." By Steve Dubyk and Sufi Mustafa. Obtained from the author.

were collected near a sewage treatment plant, four dairy operations, a poultry operation, one liquid septage facility, one sewage sludge disposal facility, and several oil and gas facilities.[142] Table 3 presents the data from the monitors near the oil and gas facilities, and a discussion of the results follows.

Table 3: Summary of Monitoring Data from New Mexico Study

Facility type	**H_2S concentration measured at monitoring site (ppb)[143]**	
	Range	**Average**
Indian Basin Hilltop, no facility	5 – 8	7
Indian Basin Compressor Station	3 – 9	6
Indian Basin Active Well Drilling Site	7 – 190	114
Indian Basin Flaring, Production, and Tank Storage Site	4 – 1,200	203
Marathon Indian Basin Refining and Tank Storage Site	2 – 370	16
Carlsbad City Limits, near 8 to 10 wells and tank storage sites	5 –7	6
Carlsbad City Limits, Tracy-A	5 – 8	7
Compressor station, dehydrators – Location A	4 –5	4
Compressor station, dehydrators – Location B	2 – 15,000	1372
Huber Flare/Dehydrating Facility [a]	4 – 12	77
Snyder Oil Well Field	2 – 5	4
Empire Abo Gas Processing Plant	1 – 1,600	300
Navajo Oil Refinery	3 – 14	7 - 8

[a] Strong winds, flare not operating correctly at time of sampling may have caused lower readings than expected, according to study, p.8.

The New Mexico data indicates that ambient concentrations of hydrogen sulfide at the sampling locations, which included both oil and gas facilities and sites without oil and gas facilities, are at least an order of magnitude greater than 0.11 to 0.33 ppb, which are the ambient levels of H_2S that can normally be expected in urban areas.[144] The ambient levels recorded at the two sites without expected sources of H_2S – Indian Basin Hilltop, no facility and Carlsbad City Limits, Tracy-A – both averaged 7 ppb, indicating that usual

[142] NMED Trip Report, p.1.
[143] The monitor that the NMED used recorded hydrogen sulfide concentrations every 30 seconds for 3 minutes. The averages reported in this table are averages of 3-minute mean concentrations.
[144] Agency for Toxic Substances and Disease Registry (ATSDR). 2004. Toxicological profile for hydrogen sulfide (*Draft for Public Comment*). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Chapter 2, p.1.

H_2S concentrations in this part of New Mexico are higher than normal urban background levels.

Hydrogen sulfide levels sampled at flaring, tank storage, and well drilling sites, averaging from approximately 100 to 200 ppb, are significantly elevated compared to normal background levels, and compared to usual background H_2S concentrations in this area of New Mexico. While these concentrations generally produce a nuisance due to odors which may translate into headaches, nausea and sleep disturbances if exposure is constant, one study discussed above (Legator et al., 2001) found central nervous system, respiratory system, and ear, nose and throat symptoms associated with annual average hydrogen sulfide levels ranging from 7 to 27 ppb. Overall, the data shows that concentrations of H_2S vary widely, even at similar facilities: at one compressor / dehydrator, the average concentration over the course of monitoring was 4 ppb, while at another, the average was 1372 ppb. The data further demonstrates that H_2S is present, often at quite elevated levels, at oil and gas facilities. A staff person at the NMED indicated that there is need for more monitoring and a better-designed study, but that budget constraints prevent them from routine monitoring. The department had rented a hydrogen sulfide monitor for this study.

6.2.1.5 North Dakota

The North Dakota State Department of Health and Consolidated Laboratories monitored hydrogen sulfide emissions from oil and gas wells at several locations, from 1980 until 1992. Each location was near at least one oil or gas well. At one location, the Lostwood Wildlife Refuge monitoring station, the highest one hour average concentration

recorded was 88 ppb, in 1990.[145] At Lone Butte, 6 miles north of the Theodore Roosevelt National Park, one hour average hydrogen sulfide concentrations frequently exceeded 200 ppb.[146] At another site, in a valley with several wells within one mile from the monitor, recorded concentrations were as high as 250 ppb.[147] These findings highlight the fact that hydrogen sulfide is routinely emitted near oil and gas wells.

These monitoring studies reveal that hydrogen sulfide is present at oil and gas facilities, including oil refineries, gas processing plants, oil and gas wells, flares, and compressor stations. These types of facilities are commonly situated near residences, where people can be routinely exposed to hydrogen sulfide. The levels of H_2S range from relatively low concentrations of 2 ppb recorded in Louisiana to the much higher concentrations observed in New Mexico and North Dakota.

6.2.2 Routine Monitoring

Of the twenty states that have an ambient hydrogen sulfide standard, only three – California, Oklahoma, and Texas – conduct routine monitoring of ambient H_2S concentrations. The other eighteen states do not monitor ambient H_2S levels. Rather, the standard is generally used in permitting facilities that emit hydrogen sulfide. Typically, the health/environmental departments model emissions and permit a facility if the model reports that the emissions would not raise ambient levels above the standard.

6.2.2.1 California

The California Air Resources Board (CARB), which manages air quality and pollution in the state, has authority to enforce the state ambient hydrogen sulfide standard

[145] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-22.
[146] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-26.
[147] EPA, "Report to Congress on Hydrogen Sulfide Emissions," p.III-30.

of 30 ppb, averaged over one hour. CARB also delegates management to the state's 35 Air Pollution Control Districts (APCDs) or Air Quality Management Districts (AQMDs), each with authority to adopt its own rules and regulations to control and monitor emissions of hydrogen sulfide. A map of the state air districts is in Appendix C. The local districts defer to the state ambient standard, but they are in charge of conducting monitoring of ambient H_2S.

The twelve sites in California where hydrogen sulfide is routinely monitored were chosen because of nearby emission sources. Table 4 summarizes the monitoring sites and the sources of H_2S. I discuss the data for 2005 from Contra Costa and Santa Barbara Counties, where the H_2S sources are due to oil and gas facilities. Daily averages of hourly hydrogen sulfide readings at the three monitoring sites in Contra Costa County range from 0.000 to 0.003 ppm, with one reading of 0.007 ppm at one monitoring site. Similarly, the daily averages of hourly H_2S concentrations recorded during 2005 at all three sites in Santa Barbara range from 0.000 to 0.001 ppm.[148] These levels are most likely of no health concern.

Table 4: California H_2S Monitoring Sites

District	County	Sites	Source(s)
Great Basin Unified APCD	Inyo	2	Geothermal Power Plant
Lake County AQMD	Lake	3	Geothermal Power Plants
Mojave Desert AQMD	San Bernardino	1	Chemical Processing Facility
San Francisco Bay Area AQMD	Contra Costa	3	Chevron Oil Refinery
Santa Barbara County APCD	Santa Barbara	3	Oil and Gas Processing Facilities

[148] Data is available at http://www.arb.ca.gov/adam/cgi-bin/db2www/adamweeklyc.d2w/start. In Step 3, select desired county, and on the next page, in Step 1, select "Daily Average of Hourly Measurements." Use arrows on the right to select different time periods.

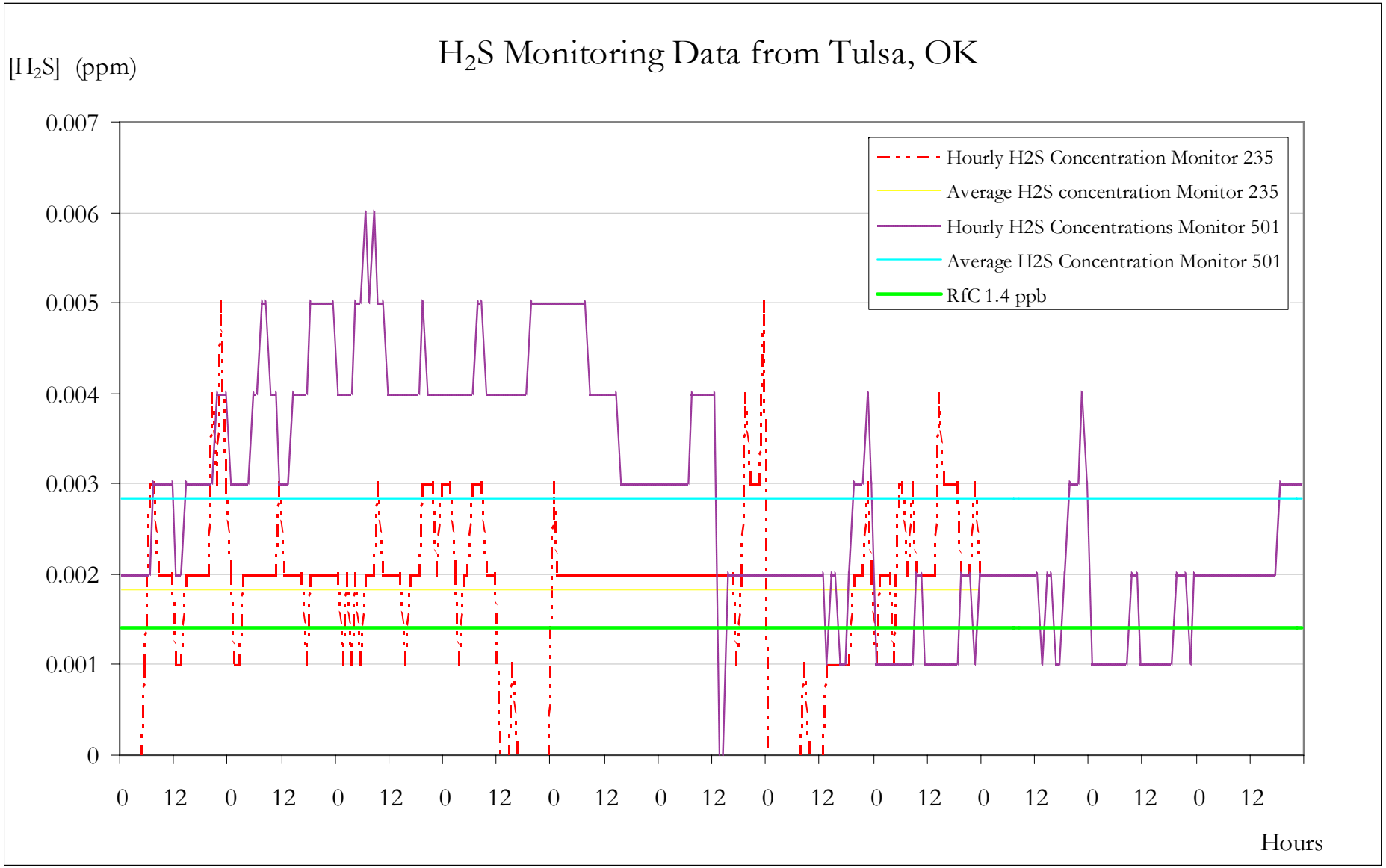
6.2.2.2 Oklahoma

The Air Quality Monitoring division of the Oklahoma Department of Environmental Quality (DEQ) continuously monitors ambient levels of hydrogen sulfide at sites downwind of two large oil refineries in Tulsa. The DEQ initiated the monitoring because complaints about foul odors numbered as many as 5 or 6 per day.[149] According to staff at the Oklahoma DEQ, the DEQ installed three monitors in Tulsa, and continuous hourly average data for two of the three monitors is available on-line.

Figure 3 summarizes the data on ambient H_2S levels recorded at these two sites in Tulsa. Monitor 235 is in a park right next to residences an eighth to a quarter of a mile downwind and across the river from a refinery. Monitor 501 is on a hill, two to three miles downwind of another refinery. The hill elevation approximately lines up with the height of the refinery stacks. The majority of the odor complaints mentioned above came from residents of this neighborhood. Now, the DEQ receives about 3 or 4 complaints a week. The levels of hydrogen sulfide in both neighborhoods, although not very high, are nevertheless above the EPA's RfC of 1.4 ppb, and are well elevated above normal background levels of 0.11 to 0.33 ppb. It is possible that continuous exposure to these levels poses health risks. While the Oklahoma DEQ is monitoring hydrogen sulfide levels, there is no concurrent community health or exposure study investigating the health effects of chronic exposure to these levels of H_2S.

[149] Personal communication, Rhonda Jeffries, Oklahoma Department of Environmental Quality. February 10, 2006.

Figure 3: Tulsa H_2S Monitoring Data[150]



[150] Data from http://www.deq.state.ok.us/aqdnew/monitoring/cpdata.htm#

6.2.2.3 Texas

The Texas Commission on Environmental Quality (TCEQ) coordinates a network of monitors across the state to insure compliance with its ambient air quality standards. Hydrogen sulfide is among the pollutants that are routinely monitored. There are twelve active H_2S monitors in Texas, some in residential and some in industrial areas, each near an oil or gas facility, including a refinery, a tank battery, and a compressor station.[151] The majority of the monitors register relatively low H_2S levels, ranging from 0.1 ppb to 5 ppb. However, one monitor at compressor station near a residence, consistently records elevated levels of H_2S. In December 2005, the last month for which the data has been validated by the TCEQ, 20 percent of the hourly readings exceeded the state standard of 0.8 ppm.[152] Chronic exposure to such levels, generally considered a nuisance due to odor, has also been shown to adversely affect human health, as discussed in the Literature Review – Chronic Exposure section.

7. Evidence From People Living Near Oil and Gas Operations

I conducted semi-structured, informal telephone interviews with people who believe that their health has been compromised as a result of exposure to hydrogen sulfide from oil and gas operations. Appendix D contains narratives of each interview, and provides details about each interviewee's experience. Some interviewees had previously contacted the Oil and Gas Accountability Project (OGAP), a non-profit organization working to reduce the impacts of oil and gas development on communities and the

[151] Data and photos are available at http://www.tceq.state.tx.us/compliance/monitoring/air/monops/sites/monitors_map.html

[152] 65 out of 332 readings were above 80 ppb. (40 data points did not include readings due to equipment maintenance).

environment, about their concerns. These interviewees identified other potential interview participants. I spoke with eleven people, and obtained information about the experiences of two additional people who lived with the interviewees. Thus, the information I present here is based on the experience of thirteen people. The ages of the interview participants range from 25 to 76. To protect the privacy of the interviewees, their names and other identifying characteristics have been withheld.

Table 4 summarizes the information on the sources of H_2S, lengths of exposure, and symptoms reported by each interviewee. Hydrogen sulfide exposure was due to emissions from a variety of sources. As identified in the interviews, these consisted of a natural gas sweetening facility, natural gas and oil well sites, flaring operations at both oil and gas facilities, venting, wastewater pits, and an oil refinery. The duration of exposure also varied, from one year to as long as eleven years, and these exposure periods in several cases include instances of acute exposure to accidental high-concentration H_2S releases. Some interviewees had information on the concentrations of H_2S to which they were exposed, while others did not.

The reported health effects are consistent with exposure to hydrogen sulfide, and include both physical and neurological symptoms. The most commonly reported symptoms were pressure headaches or dull headaches (ten people), fatigue or loss of energy (seven people), and memory impairments (seven people). Dizziness, throat irritation, eye irritation, heart palpitations, and insomnia were each reported by four people, and nosebleeds by five people. Other symptoms that the interviewees are experiencing are balance problems, trouble walking, vomiting, coughing, concentration problems, skin irritations (in some cases severe), and shortness of breath.

Eight people are experiencing chemical hypersensitivity and attribute it to hydrogen sulfide exposure. Two people I interviewed have had their gall bladders removed, which may or may not have been related to hydrogen sulfide exposure, and four have been diagnosed with chemical encephalopathy (swelling of the brain). Three interviewees are on permanent Social Security disability as a result of their health problems, which they attribute to hydrogen sulfide exposure. Five separate interviewees also stated that animals in their area were experiencing health problems. Every interviewee reported that the characteristic rotten egg odor of hydrogen sulfide was commonplace at their residences. Four families that I interviewed chose to move from their previous residences because of the health problems they associate with hydrogen sulfide.

While some of the interviewees have been diagnosed by medical professionals who attributed their symptoms to exposure to hydrogen sulfide, others have not. Oil and gas operations emit a host of other pollutants in addition to hydrogen sulfide, many of which are hazardous to human health, confounding the process of ascribing health effects to just one chemical. Additional confounders are individual health factors and the potential presence of other sources of hydrogen sulfide. This difficulty of disaggregating pollutants and symptoms provides an opportunity for critics to undermine the conclusion that the health problems reported by the people I interviewed are due to hydrogen sulfide. Nevertheless, the symptoms that the interviewees experienced match the health effects associated with hydrogen sulfide exposure as reported in the toxicological studies I present above.

The interviews provide evidence, which, although it is anecdotal, attests to the fact that hydrogen sulfide is emitted at a host of oil and gas facilities, and that its continual presence in ambient air compromises human health and well being. Although the concentrations of H_2S to which the interviewees were exposed are, for the most part, not known, they likely are not very high. Except for the three cases of knockdown, the interviews show that chronic exposure to relatively low levels of hydrogen sulfide can nevertheless take a considerable toll on people's health. The health problems that the people I interviewed are experiencing are serious enough to warrant monitoring of ambient air near oil and gas facilities in residential areas to ensure that H_2S levels are not above those considered safe. Clearly, the very issue of what levels of hydrogen sulfide are "safe" is contentious, judging in part by the wide range of values that characterize states' ambient H_2S standards. More research is certainly needed, both to determine the effects of chronic exposure to low levels of H_2S and to establish a sound standard for safe exposure to H_2S.

Table 4: Summary of Interviews

	Age and Sex	Source of Emissions	Exposure Time and Concentrations	Symptoms	Diagnosis
Story 1	Male 76	Venting from tank battery	3 years ongoing, 2 acute exposures	*Ongoing*: Staggering, dizziness, pressure headaches, dry cough, shortness of breath, throat irritation, fatigue, lightheadedness, insomnia, lack of concentration, memory loss; *Acute exposure*: stiff neck, dizziness and dry heaving	chemical encephalopathy chemical hypersensitivity due to H_2S
	Male 25	Sour gas well, tank battery	Ongoing; one acute exposure- knockdown, 200 ppm	*Knockdown*: severe headache *Persistent symptoms*: very bad memory, some balance problems	
Story 2	Female 44	Oil refinery, waste water treatment plant, oil pads	Ongoing, unknown concentrations	Headaches, balance problems, concentrations problems, eye irritation, problems sleeping, general pain, low muscle strength, trouble walking, problems with memory retention and reading comprehension, hypersensitivity of the skin	chemical encephalopathy
Story 3	Male and Female, mid-40s	Natural gas well flaring	Ongoing, unknown concentrations	*Wife*: pains similar to severe rheumatoid arthritis, blistering of the skin when showering, severe burns on the bottoms of her feet, skin covered in welts, fatigue, vomiting, rectal bleeding, severe sinus headaches; gall bladder removed *Husband*: rectal bleeding	None specific to H2S
Story 4	Male and Female, mid-60s	Amine plant, sour gas wells	Ongoing for 1 year; unknown concentrations	*Both*: chronic sore throat, congestion, coughing, headaches, swollen eyes, insomnia, occasional nosebleeds, and a general lack of energy. *Husband*: face burns, burning on hands and eyes. *Wife*: heart palpitations	None
Story 5	Male and female, mid-40s	Oil refinery, waste water treatment	Husband: occupational; ongoing residential Wife: ongoing; Concentrations 3 ppm; 3 or 4 times per week 10 ppm	*Husband*: bloody nose, headaches, colon polyps, burning eyes, throat itching, and itching all over, severe headaches, severe rashes, burning skin, teeth damage, nerve damage, slurred speech; on disability, unable to work *Wife*: rapidly deteriorating eyesight, ringing in her ears, memory problems, trouble with balance, tremors, trouble walking up and down stairs, and severe migraine headaches; gall bladder removed	chemical encephalopathy
Story 6	Female 50s	Sour natural gas wells flaring, tank battery	Ongoing; one acute exposure	*Acute exposure*: headache, extremely sick; *Later*: extreme fatigue, confusion, anxiety, heart symptoms, shaking and tremors when exposed to certain chemicals, dizziness, headaches, nosebleeds, memory and cognitive impairments, especially upon exposure to H2S or other chemicals, bronchial asthma symptoms *Son knocked down*: arrhythmia, balance problems, and pneumonia; *Currently:* nosebleeds, walks with a cane, experiences extreme headaches, confusion, brain fog, ongoing heart problems, burning lungs when he's in an area with chemicals, scaling of the skin, psoriasis, and chloro-acne	chemical encephalopathy, non-recoverable

Story 7	Male 27	Gas processing plant, wells	Ongoing, one acute exposure	Acute exposure: extreme shortness of breath, close to unconsciousness Ongoing: blurred vision, brain fog, memory impairment, excessive sleepiness, lack of energy and strength, occasional diarrhea, blood in his urine, loss of libido, abnormal heart rhythm, and anxiety-like attacks, severe and protracted involuntary muscle movements in his arms and legs.	Chemical encephalopathy, optical nerve damage
Story 8	Female 50s	Gas wells, flares, condensate pits	Ongoing occupational, one acute exposure	Acute exposure: knockdown, blinding headache, fading of consciousness Ongoing: nasal irritation, balance and memory impairment, nosebleeds, nerve inflammation	Chemical sensitivity

8. Concluding Remarks

The literature on human health and hydrogen sulfide reveals serious and lasting physiological and neurological effects associated with acute exposure. The health effects of chronic exposure to lower levels of H_2S, as documented in several studies, also include persistent physiological and neurological disturbances. Oil and gas facilities can be expected to accidentally and routinely emit hydrogen sulfide in concentrations that span a wide range and are associated with a variety of health effects. Academic studies, my conversations with health department staff, and available data from monitoring projects help establish that hydrogen sulfide is indeed present near oil and gas facilities.

Because people live near oil and gas sites, emissions of H_2S may be routinely compromising human health. The interviews I conducted with people who live close to oil and gas facilities, as well as some research reported in the Literature Review section, provide evidence of health impacts from exposure to H_2S emitted by oil and gas development. Although the anecdotal evidence from my interviews is vulnerable to criticism that other pollutants or individual health factors may be responsible for the symptoms, the reported health effects are consistent with hydrogen sulfide exposure. The fact that concentrations of H_2S to which people are exposed are often not known does not imply that hydrogen sulfide is not the cause of the observed health effects. The lack of precise exposure data is, however, one area that future research should address.

In the meanwhile, people's health needs to be protected. The proximity of oil and gas wells to people's residences is one route of exposure to hydrogen sulfide, and to other pollutants associated with oil and gas extraction. The persistence of the land ownership pattern known as 'split estate,' under which one entity owns the rights to the surface of the property and another to

the minerals under the surface, is partly responsible for the proximity of oil and gas facilities to residences. Another factor are low setbacks, the minimum distance required between an energy facility and a specific type of development.[153] For example, in Colorado, where some of the interviewees live, the residential setback requirement for oil and gas wells is 150 feet.[154] In Texas, the setback is also 150 feet,[155] while the New Mexico residential setback is just 100 feet.[156] In Alberta, Canada, the residential setback requirement for sour gas wells areas is 100 m (approximately 330 feet).[157] While greater than Colorado's and Texas's required setback, this distance may not be sufficient, as some of the interviewees were exposed to hydrogen sulfide in Alberta. To truly provide a margin of safety and protection to people who live in areas of oil and gas development, whether the facilities are on their surface property or not, greater setback distances need to be established. The siting of oil refineries and gas processing plants near residences, and conversely, building homes near existing refineries and gas plants, exposes people to a host of pollutants, including hydrogen sulfide. This is often an issue with the dimension of social and environmental justice added to questions of protecting public health.

Some technological options exist that may help mitigate the effects of hydrogen sulfide on the health of people who live near emission sources. One advanced technology for odor control, consisting of a dry scrubbing system with multiple beds of engineered media (made by soaking, or on a rotating agglomeration disk), removed hydrogen sulfide at a wastewater

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[153] http://www.eub.ca/portal/server.pt/gateway/PTARGS_0_0_257_229_0_43/http%3B/extContent/publishedcontent/publish/eub_home/public_zone/eub_process/enerfaqs/EnerFAQs5.aspx#1

[154] Colorado Oil and Gas Conservation Commission, Rule 603. Available at http://oil-gas.state.co.us/RR_Asps/600Series.pdf

[155] Texas Administrative Code, Title 16, Part I, Chapter 3, Rule 3.21 (a) and (i). Available at http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=4&ti=16&pt=1&ch=3&rl=Y

[156] Personal communication, Denny Foust, New Mexico Environment Department, April 12, 2006.

[157] Alberta Energy and Utilities Board, Directive 056, Energy Development Applications and Schedules. Available at http://www.eub.ca/docs/documents/directives/directive056.pdf, pp.54-55.

treatment facility with an efficiency of 99.94 percent.[158] This odor control technology reduced the peak inlet hydrogen sulfide concentration of 108.0 ppm to 0.061 ppm.[159] Such odor abatement technologies could be required at all facilities that emit hydrogen sulfide, including oil refineries and gas processing plants. At points of oil and gas extraction and processing, requiring high efficiency flares would ensure that less hydrogen sulfide (and other pollutants) escape into ambient air unburned.

As I show in the Regulations and Recommendations section, at the federal level, the oil and gas industry and the paper and pulp industry have exerted their influence to prevent H_2S from being included on the Clean Air Act's Hazardous Air Pollutants (HAPs) list, and to exempt it from reporting under the EPA's Toxic Release Inventory (TRI). At the time of writing, the EPA is reviewing both decisions, which at the very least indicates that some concern exists over the lack of stricter regulation of hydrogen sulfide at the federal level. The level of regulation of hydrogen sulfide varies widely across the states that have established an ambient standard in the absence of a federal one, but again, the very existence of ambient standards suggests that hydrogen sulfide is a concern.

Monitoring of ambient H_2S is necessary to determine exactly how much is being emitted and to clarify the link between exposure and health effects. Enough evidence of routine H_2S emissions at oil and gas facilities emerges from my conversations with health department personnel, interviews with people living near oil and gas sites, several studies summarized in the Literature Review section, and state monitoring projects to merit more comprehensive monitoring. The lack of federal standards for ambient H_2S levels or for emissions of H_2S is one reason for sparse monitoring even at state level, since state health / environmental departments

[158] Gailey, Karen. 2004. "Goodbye Odors, Hello Happy Neighbors." *Pollution Engineering*. p.30.
[159] Gailey, Karen. 2004. "Goodbye Odors, Hello Happy Neighbors." *Pollution Engineering*. p.30.

largely depend on federal funding for their projects. More routine and special project monitoring would facilitate conducting community health studies, by providing accurate exposure data that could be matched with observed health effects.

In light of the information presented here on the health effects associated with exposure to hydrogen sulfide, even though rigorous data on the dose-response relationship is lacking, it is irresponsible and callous to delay making some public policy decisions that would help protect human health.

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Appendix A: Guidelines for Occupational Exposure to Hydrogen Sulfide

[H_2S] (ppm)	Agency	Duration	Comments
0.1	AIHA [a]	ERPG- 1 1 hour	Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing other than mild, transient adverse health effects or perceiving a clearly defined objectionable odor; based on human odor detection.
0.33	EPA [b]	AEGL 1 8 hours	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
0.36	EPA [b]	AEGL 1 4 hours	
0.51	EPA [b]	AEGL 1 1 hour	
0.6	EPA [b]	AEGL 1 30 minutes	
0.75	EPA [b]	AEGL 1 10 minutes	
10	ACGIH [c]	TLV-TWA 8hr/day, 40hr/week	Occupational exposure
10	OSHA [d]	8hr/day, 40hr/week	Occupational exposure
10	NIOSH [e]	10 minutes	Recommended exposure time to 10 ppm in the workplace
15	ACGIH [c]	TVL-STEL Short periods of time	Occupational exposure for short periods of time
17	EPA [b]	AEGL 2 8 hours	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
20	EPA [b]	AEGL 2 4 hours	
20	OSHA [d]	Ceiling	Ceiling, if no other exceedence of 10 ppm standard
27	EPA [b]	AEGL 2 1 hour	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
30	AIHA [a]	ERPG-2 1 hour	Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take productive action; based on animal studies
31	EPA [b]	AEGL 3 8 hours	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.
32	EPA [b]	AEGL 2 30 minutes	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
37	EPA [b]	AEGL 3 4 hours	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.
41	EPA [b]	AEGL 2 10 minutes	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
50	OSHA [d]	10 minute ceiling	If no other measurable exposure during 8 hr shift
50	EPA [b]	AEGL 3 1 hour	Airborne concentration above which it is predicted that the general population, including susceptible individuals, could

59	EPA [b]	AEGL 3 30 minutes	experience life-threatening health effects or death.
76	EPA [b]	AEGL 3 10 minutes	
100	NIOSH [d]	IDLH	Immediately Dangerous to Life and Health
100	AIHA [a]	ERPG-3 1 hour	Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects; based on human studies

[a] Source: EPA, http://www.epa.gov/oppt/aegl/define.htm and http://www.epa.gov/oppt/aegl/results57.htm

[b] Source: AIHA, 2005 American Industrial Hygiene Association, available at http://www.aiha.org/1documents/Committees/ERP-erpglevels.pdf, and EPA Report, 1993 p.III-11, 13.

[c] EPA "Report to Congress on Hydrogen Sulfide Emissions," p.III-10.

[d] Occupational Safety and Health Administration, 29 CFR 1910.1000, available at http://www.osha.gov/dts/chemicalsampling/data/CH_246800.html

[e] Source: NIOSH is a department within the Centers for Disease Control and Prevention. See http://www.cdc.gov/niosh/npg/npgd0337.html for NIOSH's H_2S exposure recommendations.

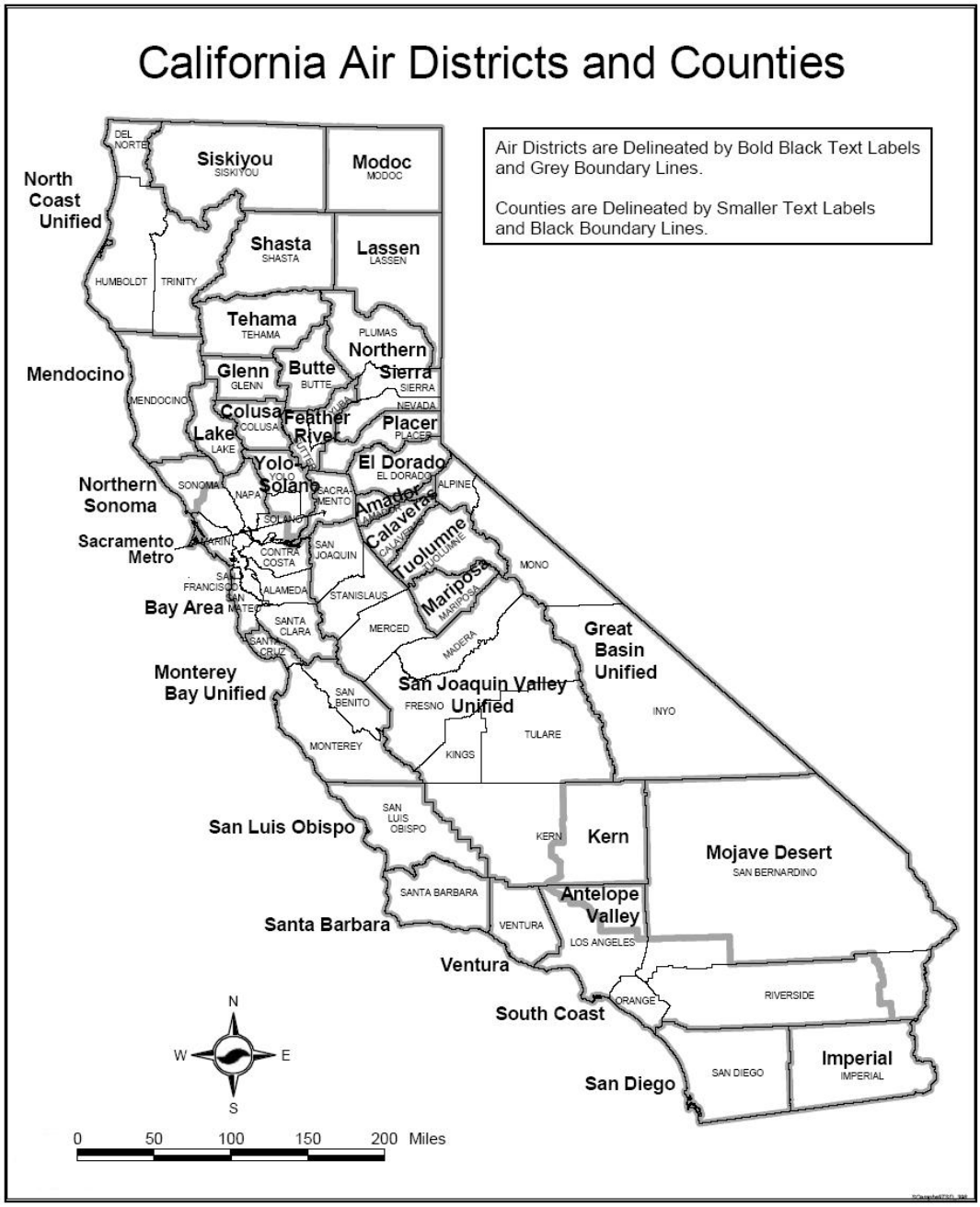
Appendix B: State Ambient Hydrogen Sulfide Standards

State	Standard	Duration	Justification	Source
Arizona	180 µg/m3 (0.128 ppm)	1 hr	AAAQG, health based, on OSHA guidelines	www.azdeq.gov/environ/air/permits/download/ambient.pdf
	110 µg /m3 (0.078ppm)	24 hr		
California	0.03 ppm	1 hr		California Air Resources Board, Nov 2005: http://www.arb.ca.gov/aqs/aaqs2.pdf
Delaware	0.06 ppm	average concentration not to be exceeded taken over any consecutive 3 minutes		Regulation 3, Delaware Ambient Air Quality Standards, www.dnrec.state.de.us/air/aqm_page/docs/pdf/reg_3.pdf
	0.03 ppm	average concentration not to be exceeded taken over any consecutive 60 minutes		
Hawaii	25 ppb	1 hr	Combination of health and nuisance	Hawaii State Ambient Air Quality Standards, www.hawaii.gov/health/environmental/air/chart.pdf
Iowa	30 ppb	1-hr daily maximum	"health effects standard"	www.legis.state.ia.us/Rules/2004/Bulletin/IAB040818.pdf
Louisiana	330 ppb	8-hr average	NIOSH/OSHA safety standard, took 1/42 of their level	Personal Communication, Jim Hazlett, Air Quality Assessment, Louisiana Department of Environmental Quality
Massachusetts	0.65 ppb	24-hr and annual limit	Based on EPA RfC, Threshold Effects Exposure Limit and Allowable Ambient Limit	Massachusetts Rule 310: Ambient Air Exposure Limits for Chemicals www.mass.gov/dep/air/aallist.pdf
Minnesota	0.05 ppm (70 µg /m3)	1/2 hr average not to be exceeded over 2 times per year		Minnesota Pollution Control Agency, State Ambient Air Quality Standards, Chapter 7009.0080 www.revisor.leg.state.mn.us/arule/7009/0080.html
	0.03 ppm (42 µg /m3)	1/2 hr average not to be exceeded over 2 times in any 5 consecutive days		
Missouri	0.05 ppm (70 µg /m3)	1/2 hr average not to be exceeded over 2 times per year		Missouri Ambient Air Quality Standards CSR 10-6.010, www.sos.mo.gov/adrules/csr/current/10csr/10c10-6a.pdf
	0.03 ppm (42 µg /m3)	1/2 hr average not to be exceeded over 2 times in any 5 consecutive days		
Montana	0.05 ppm	hourly average, not to be exceeded more than once per year	health based	Montana Rule 17-8-214 http://deq.mt.gov/dir/legal/Chapters/CH08-02.pdf
Nevada	0.08 ppm	1-hr average	health based	Nevada Chapter 445B – Air Controls, section 22097, www.leg.state.nv.us/NAC/NAC-445B.html#NAC445BSec22097
New Mexico	0.010 ppm	1-hr average not to be exceeded more than once per year		New Mexico Ambient Air Quality Standards, Title 20, Chapter 2, Part 3 www.nmenv.state.nm.us/aqb/regs/20_2_03nmac_103102.pdf
	0.100 ppm	1/2 hour average	special for the Pecos-Permian Basin Intrastate Air Quality Control Region	
	0.030 ppm	1/2 hour average	for within five miles of municipalities in Pecos-Permian Basin that are populated areas (more than 20,000 people)	

New York	0.01 ppm	1-hr average	odor and aesthetic	New York Rules and Regulations, Chapter III, Subpart 257-10; www.dec.state.ny.us/website/regs/subpart257_10.html
North Dakota	10 ppm	ceiling, maximum instantaneous concentration not to be exceeded	health based	North Dakota Ambient Air Quality Standards, Chapter 33-15-2 www.legis.nd.gov/information/acdata/html/..%5Cpdf%5C33-15-02.pdf
	0.20 ppm	maximum 1-hr average concentration not to be exceeded more than once per month		
	0.10 ppm	maximum 24-hr average concentration not to be exceeded more than once per year		
	0.02 ppm	maximum arithmetic mean concentration averaged over three consecutive months		
Oklahoma	200 ppb	24-hr average concentration		Oklahoma Air Pollution Control Rules, Title 252, Chapter 100-31-7 www.deq.state.ok.us/rules/100.pdf
Oregon	2 µg /m3 (0.3 ppb)*	annual average concentration	based on EPA's RfC, proposed benchmark	Personal Communication, Bruce Hope, Senior Environmental Toxicologist, Oregon Department of Environmental Quality, Air Quality Division. Feb. 10, 2006.
Pennsylvania	0.005 ppm	24-hr average		Pennsylvania Article III, Chapter 131, www.pacode.com/secure/data/025/chapter131/025_0131.pdf
	0.1 ppm	1-hr average		
Texas	0.08 ppm	30-min average	if the downwind concentration of hydrogen sulfide affects a property used for residential, business, or commercial purposes	Texas Administrative Code, Title 30 Part 1, Chapter 112, subchapter B; http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=30&pt=1&ch=112&sch=B&rl=Y
	0.12 ppm	30-min average	if the downwind concentration of hydrogen sulfide affects only property used for other than residential, recreational, business, or commercial purposes, such as industrial property and vacant tracts and range lands not normally occupied by people.	
Vermont	33.3 µg /m3 (0.024 ppm)	24-hr	health based	proposing 1 µg /m3 annual average, to be determined in April; current standard available at http://www.anr.state.vt.us/air/docs/apcregs.pdf
Wyoming	70 µg /m3 (0.05 ppm)	1/2 hour average not to be exceeded more than 2 times per year		Wyoming Department of Environmental Quality, Air Quality Division, Ambient Air Quality Standards, Chapter 2: http://deq.state.wy.us/aqd/stnd/Chapter2_2-3-05FINAL_CLEAN.pdf
	40 µg /m3 (0.03 ppm)	1/2 hour average not to be exceeded more than 2 times in any 5 consecutive days		

* Proposed, to be reviewed April 2, 2006

Appendix C: California Air Districts



Appendix D: Interview Narratives

Story 1

One participant, a 76-year-old rancher, used to own and live on a ranch on flat prairie land in Alberta, Canada. His property was three quarters of a mile straight east and downwind of an oil facility, which included a tank battery where impurities such as sand and salt water were removed from the oil to prepare it for the pipeline. According to government figures which he claims to have obtained, the oil initially contained 8% hydrogen sulfide. This figure increased to 13% after a few years of production. The interviewee believes that H_2S emissions affected people within a radius of up to three miles from the facility.

Venting to the atmosphere from several big tanks in the battery released hydrogen sulfide, as oil added to the tanks stirred up the settled oil, emitting H_2S. For the first three years of the facility's operation, there was no flare, and the hydrogen sulfide would accumulate and then be vented.

This interviewee was exposed to hydrogen sulfide many times before he realized what was taking place. He often woke up dizzy, and reports staggering for a half hour before regaining his balance for the rest of the day. Initially, he thought the dizziness was due to high blood pressure, but tests revealed that his blood pressure was normal. During and after every exposure, he experienced angina pains (pain due to lack of oxygen to the heart muscle) while walking even short distances. After moving away, the angina improved and he is able to control it with medication. Nevertheless, he has undergone six by-pass surgeries. Additionally, he experienced pressure inside his head and short term memory loss.

This interviewee experienced health problems as a result of several specific hydrogen sulfide releases from the tank battery. He believes he was exposed to a very high, but unknown, concentration of hydrogen sulfide on one occasion, when he was harvesting crops approximately 500 feet from the oil facility's fence line. He recalls briefly smelling the rotten egg odor, and then not noticing it further. At that time, he experienced a stiffening of the neck and shoulders, and his head 'froze' in the position he had turned it. Now, if he is exposed to hydrogen sulfide, he experiences similar but not as severe symptoms of the head, neck, and shoulders.

On another occasion, when the rotten egg odor characteristic of hydrogen sulfide was especially strong outside the house, he was sick for three days. During this episode, which he attributes to many small exposures over the three days, his balance was disrupted so that he could not stand when he stood up, and he experienced dry heaving. After this episode, he started to be observant and to study the effects of hydrogen sulfide on human health. He used the Internet and visited other people who had problems due to H_2S, and found that his symptoms matched hydrogen sulfide exposure.

The interviewee eventually purchased a hydrogen sulfide monitor, and he reports that there were short periods of time when H_2S concentrations were very high. On one occasion, his 17-year-old grandson experienced knockdown while monitoring for hydrogen sulfide on the property. The monitor recorded 200 ppm at that time. His grandson had been exposed at other times while working on the ranch, and had difficulty in school after the knockdown.

I also spoke with the grandson about his knockdown. He experienced dull headaches in the front of his head whenever he was exposed to H_2S. He remembers

having a very intense headache right before the incident. His head and neck stiffened, and he lost consciousness. Since this exposure, he has difficulty remembering details and notices his memory getting progressively worse. His balance is not as good as it used to be, and he experiences hot flashes several times per week.

The older interviewee sought medical help on many occasions because of his health problems. Eight hours of testing by an H_2S specialist ruled out Alzheimer's, Parkinson's, and Lou Gehrig's diseases, as well as progressive blindness and deafness. According to this professional's letter, which the interviewee read to me, the diagnosis was of a "75-year-old man who had extensive exposure" and now suffers from chemical encephalopathy (swelling of the brain) due to H_2S, small airways obstruction beyond that due to cigarette smoking and attributable to H_2S, SO_2, and diesel exhaust, and chemical hypersensitivity due to H_2S exposure. His symptoms are a dry cough, shortness of breath, throat irritation, fatigue, lightheadedness, dizziness, insomnia, lack of concentration, and memory loss. The symptoms that improved after moving are throat and eye irritation and balance, but the others persist.

There have also been problems with cattle in the area, including spontaneous abortions and animals' hooves falling off and not healing.

Story 2

A 44-year-old woman has suffered many health impacts from exposure to hydrogen sulfide and from an oil refinery, and there are many pump jacks, collection ponds, and tank batteries close to her residence.

The oil refinery transfers its wastewater and production water to the municipal wastewater treatment facility, which also received wastewater from a dairy facility until 2001.[160] Her husband, who was employed at the wastewater treatment facility and had previously worked for an oil company, is now on permanent Social Security Disability Leave because repeated exposure rendered him physically and psychologically unfit to work. According to a safety company monitoring data that she has seen, she reported that concentrations of 10 ppm are commonplace in the street in front of the wastewater treatment plant. A park where children play is across the street from the plant.

She believes that she is exposed to hydrogen sulfide daily or almost daily. The smell of rotten eggs is regularly present in town and at her residence. Sometimes, the odor is very strong for a short time, "a minute or so," and then she no longer detects it. She thinks this is due to concentrations above the odor threshold, which occurs between 50 and 100 ppm.[161] At other times, visitors new to the area could detect an odor while she could not. She thinks her nose is no longer as sensitive to the odor of H_2S due to chronic exposure.

As a result of her and others' complaints, the Center for Disease Control's ATSDR sent personnel to her property to monitor for H_2S. Based on the levels they found in the ambient air, ATSDR has plans to follow up with water and soil sampling on the property. Although the monitors registered H_2S, the ATSDR took no action because of a lack of health studies attributing adverse health effects to the measured levels. She does not know the exact levels of H_2S on her property.

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[160] Since then, the diary has secured a discharge permit from the state Department of Environmental Quality to treat its waters on site. The treatment amounts to holding ponds on adjacent farmland that the dairy purchased, and then discharging the water over their property.
[161] Refer to Health Effects Chart.

She also experiences headaches, balance problems, concentrations problems, eye irritation, problems sleeping, and general pain. The headaches are a daily occurrence, but the severity changes. If she leaves town for several days, the headaches stop. Other problems are low muscle strength, trouble walking, problems with memory retention and reading comprehension, and hypersensitivity of the skin. She believes some of her problems are due to sexual contact with her husband, who had been routinely exposed to much higher levels at the workplace, as high as 200 ppm on one occasion, according to a police report of the accident. Specialists have diagnosed her husband with brain damage and physical damage to the neurological and muscular system from exposure to hydrogen sulfide.

Her symptoms prompted her to seek medical help on many occasions. Because of her low muscle strength, one doctor initially diagnosed her with multiple sclerosis. He later changed the diagnosis to chemical encephalopathy along with peripheral neuropathy. Another doctor has diagnosed her with cystic fibrosis, and she is awaiting results from a breast tissue biopsy. She has experienced immune system disorders and her blood tests show abnormalities that no one can explain. Other people in the area have similar blood problems.

Story 3

A couple in their mid-40s lived for eleven years in a rural Colorado area of farmland, orchards, trees, and country roads. They have since moved from that location because of the myriad health problems they were experiencing. A natural gas well was situated directly across the street, less than a thousand feet from their residence. There

were other gas wells close to their property, including several on the mountainside nearby, where they could see many being flared. On that mountainside, there was also a big pit containing wastewater.

The property was situated amidst hills and mountains, and it was often very windy. They continually smelled a rotten egg odor from the well across the street, which caused them to complain to the company that was doing the drilling. At first, the company was responsive, shutting the well off for a few days, draining the tanks, and then turning the rig back on. Soon, however, the couple would notice the smell again, complain, and the company would again shut off the well, drain the tanks, then eventually turn them back on. After a year and a half, the company was no longer as responsive to their complaints or as prompt to take action.

There was flaring for many weeks at both gas wells. According to the husband, the company received several citations for illegal flaring. As a result of the their complaints, the company eventually removed one of the tanks. The company told them that they were smelling sour gas and that they had nothing to worry about. In addition to the smell, they were disturbed by the noise from the well. On many occasions, they would leave for the weekend to escape the noise and the odors.

The couple believe that they were continually exposed to hydrogen sulfide for eleven years from the gas well directly across the street and from a well on an adjacent plot. They did not know what they were exposed to until 2005, but based on information they have since gathered and on professional medical assessments, they believe it was hydrogen sulfide all along. They do not know to what concentrations they were exposed.

The couple experienced health problems, which they now attribute to ongoing exposure to hydrogen sulfide. The wife, who spent more time at home, experienced and continues to experience more and worse symptoms than her husband, who would leave the house during the week for work. Specifically, the wife, who had always been healthy before the gas wells started operating near their residence, experienced pains similar to severe rheumatoid arthritis, though tests did not reveal its presence in her body. She nevertheless took medication for nine years, which did not help with her pain. She also experienced blistering of the skin when showering, severe burns on the bottoms of her feet, and her skin was covered in welts. Her entire body was swollen and her throat burned. She spent months sleeping and vomiting. She also suffered from severe sinus headaches, and both husband and wife experienced rectal bleeding, as did some of their neighbors.

After moving, the wife's arthritis symptoms relaxed, but she still sleeps a lot, and undergoes spells of vomiting. Her body experienced symptoms of detoxification after moving. Eventually, her gall bladder was removed, and showed symptoms of poisoning. By this time, she had lost over 50 pounds and was malnourished. Her gall bladder was enlarged to the size of a small pineapple, and had excessive scar tissue, which the doctor attributed to toxicity. She has been experiencing one especially disturbing, and puzzling, behavior, which started after the couple moved away from their old residence near the gas wells. Although she was born and raised in Southern California and English is her native language, she now speaks with a strange, heavy accent, which at times resembles Russian, German, or Swedish. Because of the many persistent heath problems, she is no longer

considered 'insurable' by medical insurance companies, nor is she able to work. She is now on permanent Social Security disability.

In addition to their health problems, the couple believe hydrogen sulfide in the air around their former residence is responsible for causing the metal siding on their house to peel just two years after installation, although it was supposed to last for 50 years. Further, animals on their property experienced health problems. Two baby llamas died from a pneumonia-type illness, and an older llama had severe sinus problems. They put their dogs to sleep because of tumors. They tried to breed miniature poodles, but all the dogs were sterile.

Story 4

In October 2004, a couple in their mid-60s retired to a poor rural county in Texas, a known region of sour gas. There are several sour gas wells near their residence. Since March 2005, their property has been surrounded by several wells, all within one mile of their house, with one well across the street and less than a quarter of a mile away. Additionally, an amine gas treating plant where sour gas is sweetened, which also began operating in March 2005, is a half mile from their residence. According to a public record document that the wife received from the state environmental department in response to one of her complaints, "The facility receives sour natural gas and treats the gas with an amine treater to remove CO_2 and H_2S."[162]

The couple believe they are exposed to hydrogen sulfide from the amine plant and the sour wells that surround their property and that their exposure is ongoing. They have noticed that odors are worse at night. They are convinced that there are hydrogen sulfide

[162] Personal communication, February 27, 2006.

emissions because of the fact that the region is know for sour gas, because the amine plant's purpose is to sweeten sour gas, and because they have read a permit from the state allowing the amine plant to emit up to four pounds of H_2S per hour into the air. They often notice a strong rotten egg odor, as well as other chemical smells, including a sweet smell. (The latter may be due to benzene, or to high levels of H_2S, which has been reported to produce a sickening, sweet smell in concentrations above 30 ppm.[163]) The couple acknowledge that there are other pollutants emitted into the air that they do not know about. There has been no monitoring done on their property, and they do not know to what concentrations they are exposed.

Both husband and wife have experienced a host of adverse health effects since the gas wells and the amine plant began operating. Though neither smokes, nor ever has, they are both experiencing a chronic sore throat. Their other symptoms include congestion, coughing, headaches, swollen eyes, insomnia, occasional nosebleeds, and a general lack of energy. The husband's face burns, as do his hands and eyes. The wife has experienced heart palpitations and is now on heart medication, though she was entirely healthy before moving. They have both seen doctors many times because of their problems, including several visits to the emergency room, but neither has been officially diagnosed with hydrogen sulfide exposure. However, they think this is due to the general lack of knowledge about the subject.

On many occasions, they have been awakened by rotten egg fumes that choked, and burned their eyes, nose, and throat, and made them feel dizzy. At these times, they

[163] Snyder, Jack W., MD, PhD. et al. 1995. "Occupational Fatality and Persistent Neurological Sequelae After Mass Exposure to Hydrogen Sulfide." *American Journal of Emergency Medicine*. p. 200.

leave the house and stay in a hotel, and now have a packed suitcase ready in case they need to evacuate in a hurry.

Story 5

A New Mexico couple in their late 40s live a quarter to a half mile from a municipal wastewater treatment facility, which has been receiving wastewater from an oil refinery since 1992. The oil refinery itself is four miles from the couple's residence, and there are several oil fields in the vicinity. The refinery has been there since the 1970s, but until 1992, it injected its wastewater into the ground. The wastewater facility used to receive water from a dairy operation as well.

At their residence, the couple are routinely exposed to hydrogen sulfide, which emanates from the water at the treatment facility. The husband used to work at the wastewater treatment facility, so he was exposed to H_2S more frequently, and to higher concentrations than his wife. Accordingly, his symptoms are much more severe. The couple own an H2S monitor, which sounds an alarm at 10 ppm, a daily occurrence inside and outside the house, and while driving in town. A monitor within the gates of the wastewater facility in the past registered 375 ppm, prompting the facility to be temporarily shut down. Additionally, staff from the Centers for Disease Control (CDC) were in the area for six weeks, studying hydrogen sulfide. They placed two monitors on the couple's property, and although the official results are not yet ready, the CDC staff acknowledged that conditions are bad.

The husband's blood tests showed abnormally high levels of H2S, levels so high that the examining physician thought the sample was from a deceased man. Doctors have also confirmed that the wife has been exposed to hydrogen sulfide. The husband's health

has been deteriorating since 1992, when the refinery started discharging wastewater into the municipal wastewater treatment facility. His symptoms include nosebleeds, headaches, burning eyes, throat itching, itching all over his body, severe headaches, and severe rashes. His skin burns when he sweats. His teeth have been damaged, and he has suffered nerve damage and slurred speech. The wife has experienced rapidly deteriorating eyesight, ringing in her ears, memory problems, has had her gall bladder removed, and, since 1995, has trouble with balance, tremors, trouble walking up and down stairs, and severe migraine headaches.

Both have been examined by several H_2S specialists, and both have been diagnosed with chemical encephalopathy. Each time they are tested, the results are worse. The husband is permanently and totally disabled, and is on Social Security disability.

Story 6

This interviewee lived on a 640 acre farm in a relatively flat prairie areas with some undulating hills in Alberta, Canada. A natural gas well said to contain one percent hydrogen sulfide was situated about a third of a mile from the residence. There were other gas wells in the vicinity of her property, and gas was piped from these wells to a site about a mile away, where it was flared. Within three miles from the residence, there were at least a dozen natural gas wells, all with hydrogen sulfide content of one percent. There was also a battery three miles away.

Her first serious exposure occurred as a result of flaring during an initial test soon after the closest well to her house was drilled. The flaring created a jet plane-like sound, shaking the house. At this time, she experienced a headache and felt extremely sick. Her

20-year-old son, who was out walking in the field when the incident occurred, experienced knockdown. He staggered into the house, lost his balance, and collapsed. His skin was a greenish gray color when he collapsed. She contacted a regulatory body, which asked the company to stop operations. However, next day the wells were operating again. This flaring continued for a week, continually exposing her and her family to H2S. She smelled the rotten egg odor of hydrogen sulfide, and the company told her that 1 ppm of H2S was blowing to the residence. They continued to smell H2S several times per week. There has been no monitoring to determine the exact concentrations of H2S at her residence.

Within a month of the acute exposure, she was experiencing extreme fatigue, confusion, anxiety, heart symptoms, shaking and tremors, dizziness, headaches, nosebleeds, memory and cognitive impairments. Exposure to H2S or other chemicals would aggravate many of her symptoms. She also has bronchial asthma symptoms though she has never smoked. Her son developed heart arrhythmia, balance problems, and pneumonia three months after the knockdown. He now walks with a cane, experiences extreme headaches, confusion, ongoing heart problems, skin conditions including psoriasis, and burning in his lungs when exposed to chemicals. Both the interviewee and her son have multiple chemical sensitivities. An H2S specialist has diagnosed them with non-recoverable chemical encephalopathy.

Other people in the area have experienced respiratory problems, and there have been many effects on animals, including abortions and cattle's hooves falling off.

Story 7

A 27 year-old interviewee lived half a mile from a gas plant, and a little over half a mile from several oil wells with flares. He has since moved to another residence in the same Alabama county, where over 500 oil and gas are active, and he is still exposed to hydrogen sulfide.

He is convinced that he is continually exposed to hydrogen sulfide because of the presence of the rotten egg odor. The results of a monitoring project at his residence confirm the presence of H2S in concentrations of 10 ppb.[164] In addition to his ongoing exposure, the interviewee recalls nearly experiencing knockdown on one occasion while driving by a sour gas plant about five miles from his former residence. The source of that exposure was a flare at the plant, but the concentration of hydrogen sulfide is not known. At that time, he experienced shortness of breath and felt very near unconsciousness.

When he first moved to his previous residence, he started experiencing blurred vision and a loss of energy. His current health problems consist of brain fog, memory impairment, excessive sleepiness, and a lack of energy and strength. He has also experienced diarrhea, blood in his urine, loss of libido, abnormal heart rhythm, and anxiety-like attacks. Sometimes, he experiences severe and protracted involuntary muscle movements in his arms and legs that last up to a day. Exposure to hydrogen sulfide aggravates his existing symptoms. Since moving to the new residence, his heart symptoms have lessened.

He has seen several doctors about his health problems. One doctor diagnosed him with optic nerve damage, and another with chemical encephalopathy. He has tested

[164] Monitoring done by Lisa Sumi, Research Director, Oil and Gas Accountability Project. August 2005, using Jerome 631 H2S monitor. Data used with permission.

negative for a host of diseases, including Parkinson's. Though he is 27, he said he feels 67, and that not a day goes by when he feels normal.

Cats at his old residence were also affected. They experienced vomiting and weight loss, and exhibited sexually confused behavior.

Story 8:

This interviewee, a woman in her 50s, is in the process of moving to eastern Texas from her western Colorado home, where she has lived for ten years and worked as an irrigator. There are two natural gas wells about a mile downwind of her residence, and a shut in well across the street. Flaring and open condensate pits were common at these wells.

Although this interviewee experienced symptoms at her residence, her primary exposure to hydrogen sulfide was while she was working in the area, because many wells dot the fields she was irrigating. She started working near the gas wells in March 2005. One well pad was very close to the inlet for the irrigation water. Within a month, she began experiencing burning and swelling in her nasal passages. Several treatments with antibiotics did not clear her symptoms, and her doctor conceded that he did not know what was causing her problems. After this experience, she began wearing a charcoal filter mask.

Her single major exposure, which resulted in a knockdown, occurred one evening when she was getting out of her truck to turn off the irrigation water. She was approximately 50 feet from the well, when she experienced a blinding headache that made her feel like her head would burst. She then started to collapse and black out. She caught the door of her truck and was dangling there for about five minutes. Her headache then

abated and she started to smell the rotten egg odor of hydrogen sulfide, though she did not smell it when the headache started.

Since the knockdown, this interviewee has developed chemical sensitivities, and her doctor has advised her to move. She requires a respirator to be outside, and even with the respirator, she can only be outside for about an hour. She has installed three air scrubbers to purify the air in her house.

She experiences burning around her eyes and on the exposed skin on her face. Her sinuses burn and itch, and she frequently gets nosebleeds. If she is outside for more than an hour, even with the respirator, she develops ulcers on her tongue and in her mouth, and eventually the glands in her neck and armpits swell. If she ignores these symptoms, she gets nauseated and experiences vomiting and explosive diarrhea. She also has nerve inflammation in her legs, and her balance and short term memory are impaired.

The source of hydrogen sulfide, she believes, are fugitive emissions from the wells, and especially from open condensate tanks. A stack flare was also operating within a mile of her house. No tests have been done to confirm the presence of hydrogen sulfide.

Other people in her area have also been affected. One neighbor has been feeling nauseated, while many people smell the odors from the wells and have upper respiratory infections. The interviewee's new mule, which grazes on land near the wells, has experienced hair falling out. A horse also had his mane thin out and experienced diarrhea during flaring. The horse's hooves fell apart and would not heal, so the interviewee had him put down.

Exhibit 58

HYDROGEN SULFIDE:
EVALUATION OF CURRENT CALIFORNIA AIR QUALITY STANDARDS WITH RESPECT TO PROTECTION OF CHILDREN

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