Health Consultation

POSSIBLE HEALTH IMPLICATIONS FROM EXPOSURE
TO SULFUR GASES EMITTED FROM
CHINESE-MANUFACTURED DRYWALL

MAY 2, 2014

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
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A health consultation is a verbal or written response from ATSDR or ATSDR's Cooperative Agreement Partners to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR or ATSDR's Cooperative Agreement Partner which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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HEALTH CONSULTATION

POSSIBLE HEALTH IMPLICATIONS FROM EXPOSURE TO SULFUR GASES EMITTED FROM CHINESE-MANUFACTURED DRYWALL

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Agency for Toxic Substances and Disease Registry
Division of Community Health Investigations

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Executive Summary -

Background

Some U.S. homes built between 2001 and 2008 contain problem drywall (see definition on page 6). Beginning around 2008, some people living in these homes started reporting health issues and other problems to their state health agencies. Those living in affected homes reported a spectrum of symptoms and health effects including recurrent headaches, irritated and itchy eyes and skin, difficulty in breathing, persistent cough, runny noses, sinus infections and congestion, sore throats, frequent nosebleeds, and asthma attacks. Many of these residents reported that symptoms decreased or went away entirely when they left their homes and then reappeared when they returned home. Non health-related problems included a strong sulfur smell and premature corrosion or deterioration of certain metal components in their homes like air conditioner coils and wiring behind electrical outlets and inside electrical panel boxes.

Purpose

- In early 2009, the U.S. Consumer Product Safety Commission (CPSC) began investigating the problem with support from the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), the U.S. Centers for Disease Control and Prevention (CDC), and other federal and state agencies. As part of the investigation to determine possible health risks, CPSC contracted with Lawrence Berkeley National Laboratory (LBNL) to measure chemical emissions from drywall samples manufactured in China and in North America.
- In 2011, the CDC/ATSDR and the CPSC agreed that further evaluating LBNL results might provide useful information on the possibility of adverse health effects from sulfur compound exposures. ATSDR agreed to model LBNL's sulfur compound emission rates to estimate concentrations in indoor air.
- The purpose of this health consultation is to determine if exposure to the estimated - contaminant concentrations could result in adverse symptoms or health effects. -

Methods

In 2009, LBNL measured the chemical emission rates from 30 convenience drywall samples. These drywall samples were manufactured in China during 2005, 2006, and 2009 and in North America during 2009. In 2010, LBNL retested the emissions from four of the drywall samples manufactured in China and one of the samples manufactured in North America. In 2012-2013, The Georgia Institute of Technology (GA Tech), under a cooperative agreement with ATSDR, modeled the LBNL data and provided indoor concentration estimates for sulfur dioxide and the following reduced sulfur compounds: hydrogen sulfide, carbonyl sulfide, methyl mercaptan, ethyl mercaptan, dimethyl sulfide, and carbon disulfide. ATSDR compared the estimated indoor air contaminant concentrations in the GA Tech report with toxicological and epidemiological information to determine if exposures to the estimated levels could result in adverse health effects for building occupants.

Conclusions

People who were exposed to hydrogen sulfide and other sulfur compounds emitted by some drywall manufactured in China may have experienced adverse health effects or a reduced quality of life. The available data cannot be used to determine if people are still being exposed to levels that could cause health effects or adversely affect quality of life.

1. - <u>For the drywall samples manufactured in China between 2005 and 2006</u>
    - Based on the limited number of drywall samples tested, exposures to the estimated levels of hydrogen sulfide and sulfur dioxide from drywall samples manufactured in China between 2005 and 2006 were a public health concern. Short-term exposures might result in effects seen in both clinical and human epidemiologic studies. These include exacerbation of pre-existing respiratory conditions, eye and nasal irritation, headache, changes in vision, and weakness. Although less certain, longer term exposures may have increased the risk of damage to nasal tissue. Exposure to the estimated contaminant concentrations could diminish a resident's quality of life by triggering irritant (eye, nose, and throat) and physical (respiratory, gastrointestinal) symptoms, leading to negative mood states, and altering daily activities.
    - The estimated contaminant concentrations increased with increasing temperature and - humidity. -
    - Given the more than 90% reduction in hydrogen sulfide emission rates between the 2009 and 2010 laboratory testing, estimated contaminant concentrations from drywall samples were likely higher closer to their 2005-2006 date of manufacture.
    - Estimated contaminant concentrations from the drywall samples tested are consistent with levels resulting in the severe metal corrosion observed in homes.

2. - <u>For the drywall samples manufactured in China in 2009</u>
    - Based on the limited number of drywall samples tested, long-term exposures to the estimated levels of hydrogen sulfide from drywall samples manufactured in China in 2009 may have posed a public health concern for sensitive people (e.g., those with asthma).

3. - <u>For the drywall samples manufactured in China in 2005, 2006 and 2009</u>
    - Current contaminant levels cannot be estimated with the data available for the drywall samples manufactured in China in 2005, 2006, and 2009. Therefore, the potential hazard, if any, from current exposures cannot be assessed based on the 2009-2010 laboratory data.

4. - <u>For the drywall samples manufactured in North America in 2009</u>
    - Based on the limited number of drywall samples tested, exposures to the estimated contaminant levels from drywall samples manufactured in North America in 2009 were below levels of public health concern. It should be noted that these samples were not identified by CPSC as problem drywall.

NOTE: Because of the small number of drywall samples tested, these conclusions do not represent the range of all possible sulfur compound concentrations and should not be generalized to all drywall manufactured during the period of concern.

Recommendations

1. ATSDR recommends that people with health symptoms or health effects they feel are associated with living in a home with problem drywall provide this ATSDR health consultation report to their health care provider.

2. ATSDR recommends that residents in homes with drywall that meet the CPSC problem drywall case definition follow the CPSC/U.S. Department of Housing and Urban Development (HUD) remediation guidance. This guidance is available at: http://www.cpsc.gov/en/safety-education/safety-education-centers/drywall-information-center/ .

Additional Resources

ATSDR is working with the Pediatric Environmental Health Specialty Units (PEHSUs) and the Association of Occupational Environmental Clinics to provide updated guidance to health care providers and the public.

This health consultation, the updated PEHSU guidance, the GA Tech modeling reports, and other problem drywall resources will be available on the ATSDR drywall Web site (http://www.atsdr.cdc.gov/drywall/).

Background and Statement of Issues -

Drywall manufactured in China was imported into the United States to address the shortage of essential construction materials created by a national demand for new home construction and rebuilding after the record-breaking 2004 and 2005 hurricane seasons. In 2008, Florida homeowners began reporting upper respiratory irritation and copper corrosion in their recently built homes (2001-2008) to the Florida Department of Health (FLDOH). In January 2009, FLDOH initiated a preliminary investigation into the use of problem drywall in newly constructed homes. Residents reported premature failures of central air conditioning system evaporator coils and intermittent failure of appliances and/or electronic devices [FLDOH, 2010]. Consumer Product Safety Commission (CSPC) staff inspections noted corrosion of bare copper electrical wiring and the presence of sooty material on electrical wires [CPSC, 2009]. State and federal investigators observed tarnishing and pitting of other metallic surfaces in the affected homes in Florida and Louisiana. As of February 2013, CPSC had received over 4,000 complaints from U.S. residents in 44 states living in homes with these problems [CPSC, 2013].

Those living in affected homes reported a spectrum of symptoms and health effects including recurrent headaches, irritated and itchy eyes and skin, difficulty breathing, persistent cough, runny nose, sinus infections and congestion, sore throats, frequent nosebleeds, and asthma attacks. Many of these residents reported that symptoms lessened or went away entirely when they left their homes and then reappeared when they returned home [CPSC, 2009]. In an informal survey of more than 400 callers to the Louisiana Department of Health and Hospitals, the most common complaint reported was the presence of sulfur-like or other unusual odors [LDHH, 2010].

In addition to the health issues listed above, residents reported the following problems to the Agency for Toxic Substances and Disease Registry (ATSDR): extreme fatigue, weight loss, burned corneas, neurological issues (including peripheral neuropathy), muscular pain, vaginal burns, scarring of the esophagus, scarred lungs, blood pressure problems, kidney problems, and worsening of chronic obstructive pulmonary disease (COPD).

ATSDR and the Centers for Disease Control and Prevention (CDC) recognize the concerns of people exposed to contaminants from problem drywall. Since 2009, CDC/ATSDR has provided public health expertise in support of the CPSC's leadership of the federal response to concerns with problem drywall. Other partners include the U.S. Environmental Protection Agency (EPA), the U.S. Department of Housing and Urban Development (HUD), FLDOH, the Louisiana Department of Health and Hospitals, the Virginia Department of Health, other state and local health and environmental agencies, and the Association of Occupational and Environmental Health Clinics (AOEC).

Problem Drywall

Residents in homes with problem drywall report having health issues like respiratory irritation, and other problems such as copper corrosion and sulfur odors.

Not all of the homes contain drywall manufactured in China. Some problem homes contain drywall manufactured in North America and some have drywall with no indication of origin. When ATSDR uses the phrase "problem drywall" in this document, we are referring to all homes with the problem, regardless of the drywall's country of origin.

CPSC did not select North American drywall samples thought to be problem drywall. The intent of the LBNL analysis was to compare problem drywall from China to typical drywall manufactured in North America.

As part of the federal drywall investigation, in 2009 CPSC funded the Lawrence Berkley National Laboratory (LBNL) to measure volatile sulfur compound emission rates from a limited number of drywall samples manufactured in China (Number= 17) and North America (Number= 13). LBNL test results found the following reduced sulfur compounds (RSCs): hydrogen sulfide (H_2S), carbon disulfide, methyl mercaptan, dimethyl sulfide, carbonyl sulfide, and ethyl mercaptan. Sulfur dioxide (SO_2) was also detected. In 2012, under a Cooperative Agreement with ATSDR, the Georgia Institute of Technology (GA Tech) used the LBNL results to mathematically estimate indoor air concentrations of these contaminants.

ATSDR evaluated GA Tech modeling results to assess whether people may have been at risk for adverse health effects. To do this, ATSDR reviewed and summarized the estimated indoor air concentrations of individual RSCs, SO_2, and total RSCs (TRSCs). Then ATSDR compared the estimated contaminant concentrations to health-based screening values (also referred to as comparison values). If screening values were exceeded, the concentrations were compared to those found in human and animal studies to determine if exposures were at levels that might harm people's health. Because LBNL testing occurred in 2009 and 2010, data are not available to assess the health risk from current exposures.

Laboratory Contaminant Emission Rate Tests

The CPSC provided 30 drywall samples to LBNL: 17 were manufactured in China (9 during 2005-2006 and 8 during 2009) and 13 were manufactured in North America in 2009. CPSC collected the samples from drywall manufacturers, suppliers, and warehouses.[1] These were convenience samples and were not selected by manufacturer, date of manufacture, or possible sulfur compound emission rates. The LBNL researchers were blinded to country of origin. Documentation on storage history of the drywall samples was not available to LBNL researchers. In order for contaminant emissions from samples to reach a steady state at a constant temperature and humidity, they were fully conditioned in chambers for a period of several months. The LBNL analyses were done in two phases and released in two reports [LBNL 2010, LBNL 2011]. Phase I (2009 analysis) studied SO_2 and RSC emission rates for all 30 drywall samples under constant temperature and humidity. Phase II (2010 analysis) retested five drywall samples under varying temperature and relative humidity. Table 1 displays the different temperature and humidity conditions.

Table 1. LBNL drywall sample temperature and relative humidity test conditions[1]

	Temperature °C (°F)	Percent Relative Humidity
Phase I	25 (77)	50
Phase II	25 (77)	3.4, 49, 87
	32 (89.6)	3.4, 49, 87
	41 (105.8)	3.4, 49, 87

[1]Phase 1- LBNL, 2010; Phase II – LBNL, 2011.

[1] An approximate 1 square foot section was cut from each board and individually heat sealed in inert (Tedlar®) bags (by CPSC). After opening, LBNL maintained the samples under inert conditions prior to analysis and in between test years. For more information on sample storage and handling please see the "LBNL Chamber Emissions Study, October 2010," and the "LBNL Problem Drywall Chamber Emissions Phase 2 Report and Staff Cover Memo: September 15, 2011" at CPSC's Web site: http://www.cpsc.gov/Safety-Education/Safety-Education-Centers/Drywall/Topics/Interagency-Drywall-Investigation/.

Modeled Indoor Air Concentrations

GA Tech estimated indoor air contaminant concentrations of drywall samples from China and North America using both LBNL Phase I and II emission results using two different approaches: the "IH MOD" model and a regression model [AIHA 2009; GA Tech, 2013]. "IH MOD" is a box model and provides a conservative (protective) health interpretation. GA Tech developed an empirical model (regression analysis) to estimate possible contaminant concentrations using mean temperature and humidity values measured in the homes tested in two previous drywall investigations [GA Tech, 2013].

These results represent only a "snapshot in time" estimation of concentrations because data for four important variables were unavailable and could not be included in the models. These four variables include emission source degradation rates, chemical reactions between these sulfur compounds, contaminant indoor half-life, and deposition rates of contaminants on to surfaces (or sinks) in the home. An exponential decrease in emission rates of some volatile contaminants in household building materials during the first year or two after installation has been reported [Park, 2006]. SO_2 and RSCs "react" and degrade both in the air and on surfaces.

Housing characteristics (drywall surface area, air exchange rate, temperature, and humidity) that were measured in two drywall investigations by CPSC and the EPA/FLDOH (Table 2) were used as input into the models, as appropriate [EHHE, 2010; CPSC, 2009 "Tab C"]. House volume was calculated from the drywall surface area measurements, and it was assumed the entire house was one room with a 2.44-meter wall height. Drywall area and room volume calculations did not factor in windows or doorways. The average (mean) housing characteristic values were used to evaluate possible health implications of living in a home under "typical" temperature and humidity conditions. The information from the two drywall indoor air investigations was used to represent homes built with imported problem drywall. It reflects homes in the highest-affected states, years built, building materials used, and similar energy saving efficiencies.

Using IH MOD, GA Tech estimated contaminant concentrations using LBNL temperature and relative humidity (RH) conditions:

- Phase I LBNL emission rates from samples run under 25^{o}C and 50% RH,
- Phase II LBNL emission rates from samples run under 25^{o}C and 49% RH to roughly estimate - contaminant concentration reductions between LBNL Phase I (2009) and Phase II (2010), -
- Phase II LBNL emission rates from samples run under remaining temperature and RH (see Table 1), and
- The average of drywall samples' estimated contaminant concentrations for drywall manufactured in China. This average was calculated using both LBNL Phase I and II contaminant emission rates.

For the regression analysis (GA Tech Empirical Model), GA Tech used Phase I emission rates and mean temperature RH levels in homes measured in the 2009 CPSC and EPA/FDOH investigations (Table 2) [EHHE, 2010; CPSC, 2009].

Table 2. Housing characteristic variables used in the GA Tech empirical model[1]

	Room Volume[2] (m^3)	Temperature ^{o}C (^{o}F)	Relative Humidity (%)	Air Exchange Rate (m^3/hour)
Mean	626.1	25.4 (77.7)	60	0.22

[1]*Source:* EHHE, 2010 and CPSC, 2009 "Tab C;" [2]Calculated using drywall surface area data of housing characteristics from EHHE, 2010 and CPSC, 2009 "Tab C."

Emission Rate Testing and Modeling Results

Sulfur Compound Emission Rates

LBNL's 2009 and 2010[2] analyses found sulfur dioxide (SO_2) and the following reduced sulfur compounds (RSCs): hydrogen sulfide (H_2S), carbon disulfide, methyl mercaptan, dimethyl sulfide, carbonyl sulfide, and ethyl mercaptan [LBNL, 2010; LBNL, 2011]. These compounds were found in both Chinese and North American drywall samples. Overall, emission rates in samples from China were higher than those from North America.

GA Tech IH MOD Results

Tables 3 and 4 summarize the estimated indoor air RSC and SO_2 concentrations based on LBNL 2009 (Phase I) and 2010 (Phase II) results. Table 3 presents results of the four highest emitting samples from China, the average of these samples, the average of all samples manufactured in China in 2005 and 2006, the average of samples manufactured in 2009, and one 2009 North American sample that LBNL reanalyzed in Phase II. As LBNL did not retest all of the drywall samples in their Phase II analyses, only the average of four highest-emitting samples from China and the one North American sample can be compared. The other averaged values presented in Table 3 allow a comparison of estimated concentrations by manufacture date.

Table 3. Estimated (IHMOD Model) steady-state concentrations (µg/m^3) using 2009 LBNL (Phase I) contaminant emission rates (25°C, 50% relative humidity)[1]

Origin-date[2]	Sample-CPSC ID	H_2S	CS_2	MM	DMS	OCS	EM	SO_2
C—2006	C3—7339	403.67	9.90	6.17	2.62	NI[3]	NI	274.49
C—2006	C4—8357	606.84	13.44	6.81	2.16	5.61	NI	396.52
C—2006	C16—9672	220.27	0.83	1.82	0.12	12.12	NI	68.33
C—2005	C17—9673	657.77	2.16	4.90	0.19	27.41	0.31	314.44
C-2005+2006 (n=4)[4]	Average	472.13	6.58	5.00	1.27	11.29	---	263.45
C-2005+2006 (n=9)[5]	Average	273.03	4.87	3.02	1.23	11.62	0.31	159.44
C-2009 (n=8)[6]	Average	29.72	0.25	1.11	0.09	11.22	0.19	39.07
NA—2009	NA4—8037	NI	2.53	NI	1.08	NI	NI	NI

[1]*Source:* GA Tech, 2013 (Table 6A) and LBNL, 2010; [2]China (C), North America (NA); [3]Not Identified (NI) in LBNL analyses; [4]Average of four highest-emitting samples from China manufactured between 2005—2006: C3, 4, 16, and 17; [5]Average of all nine samples from China manufactured between 2005—2006; [6]Average for all eight samples from China manufactured in 2009. H_2S—hydrogen sulfide; CS_2—carbon disulfide; MM—methyl mercaptan; DMS—dimethyl sulfide; OCS—carbonyl sulfide; EM—ethyl mercaptan; and SO_2—sulfur dioxide.

[2] Note that in Phase II (LBNL, 2011) LBNL only tested the four highest-emitting samples from China and one sample from North America.

Table 4. Estimated (IH MOD Model) steady-state concentrations (µg/m^3) using 2010 LBNL (Phase II) contaminant emission rates (25°C, 49% relative humidity)[1]

Origin-date[2]	Sample-CPSC ID	H_2S	CS_2	MM	DMS	OCS	EM	SO_2
C—2006	C3—7339	25.65	0.49	1.91	0.09	4.69	0.34	41.19
C—2006	C4—8357	11.32	0.22	1.17	0.06	4.59	0.56	59.48
C—2006	C16—9672	17.02	0.15	1.33	0.09	6.23	0.22	51.55
C—2005	C17—9673	25.47	0.12	1.91	0.12	4.35	0.37	22.32
C-2005+2006 (n=4)[3]	Average	19.87	0.25	1.58	0.09	4.96	0.37	43.64
NA—2009	NA4—8037	8.11	0.03	0.37	0.06	3.39	0.15	4.90

[1]*Source*: GA Tech, 2013 (Table 6B) and LBNL, 2010; [2]China (C), North America (NA); [3]Average of four highest-emitting samples manufactured between 2005—2006: C3, 4, 16, and 17. H_2S—hydrogen sulfide; CS_2—carbon disulfide; MM—methyl mercaptan; DMS—dimethyl sulfide; OCS—carbonyl sulfide; EM—ethyl mercaptan; and SO_2—sulfur dioxide.

GA Tech Regression Model Results (GA Tech Empirical Model)

Table 5 displays GA Tech's estimated contaminant concentrations using regression analysis of the LBNL Phase II emission rates and the mean temperature and humidity conditions (Table 2) measured in the CPSC and EPA/FLDOH investigations [EHHE, 2010; CPSC, 2009 "Tab C"]. Except for SO_2, concentrations were generally higher when the humidity increased from 49% (Table 4) to 60% (Table 5).

Table 5. Estimated (empirical model) steady-state concentrations (µg/m3) using regression analysis and 2010 LBNL (Phase II) contaminant emission rates (25.4°C, 60% relative humidity)[1]

Origin-date[2]	Sample-CPSC ID	H_2S	CS_2	MM	DMS	OCS	EM	SO_2
C—2006	C3—7339	26.99	0.97	1.50	0.07	5.80	0.27	13.03
C—2006	C4—8357	28.93	0.41	2.13	0.07	5.34	0.70	24.29
C—2006	C16—9672	22.95	0.20	1.55	0.10	6.24	0.30	14.52
C—2005	C17—9673	23.76	0.22	1.83	0.10	4.64	0.37	9.86
C-2005+2006 (n=4)[3]	Average	25.54	0.36	1.73	0.08	5.47	0.38	14.59
NA—2009	NA4—8037	8.28	0.04	0.54	0.06	3.08	0.18	6.61

[1]*Source*: GA Tech, 2013 (Table 8) and LBNL, 2011; [2]China (C), North America (NA), year manufactured; [3]Average of four highest-emitting samples manufactured between 2005—2006: C3, 4, 16, and 17. H_2S—hydrogen sulfide; CS_2—carbon disulfide; MM—methyl mercaptan; DMS—dimethyl sulfide; OCS—carbonyl sulfide; EM—ethyl mercaptan; and SO_2—sulfur dioxide.

In Phase II, LBNL measured emission rates under three temperatures and humidities for four of the highest-emitting samples from China and one sample from North America. Table 6 displays estimated RSC and SO_2 concentrations for the highest H_2S-emitting sample (in the 2009 analysis), the average of the four highest-emitting samples, and a North American drywall sample.

Table 7 shows estimated indoor H_2S concentrations under varying temperature and relative humidity conditions, for the four highest emitting samples, the average, and a North American sample. Note that the sample with the highest H_2S emissions (C4-9673) measured in 2009 at room temperature and humidity was not the highest emitter under all temperature and humidity conditions in the 2010 LBNL testing. The emission rates are not linear and varied by drywall sample.

Table 6. Estimated (empirical model) contaminant concentrations (µg/m^3) from three drywall samples as a function of temperature and humidity used in the 2010 LBNL chamber studies[1]

	C17—9673[2]			C –Average[3]			NA4 –8037[4]		
H_2S	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp. 25°C	1.91	25.47	54.02	9.27	19.86	46.65	3.61	8.11	5.43
Temp. 32°C	31.57	51.92	54.64	25.04	40.12	63.17	2.16	15.36	18.22
Temp. 41°C	82.91	156.82	166.81	57.54	101.36	139.64	6.23	14.71	36.11
CS_2	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp. 25°C	0.06	0.12	1.11	0.08	0.25	1.61	0.03	0.03	0.12
Temp. 32°C	0.12	0.28	1.45	0.16	0.62	4.83	0.03	0.03	0.19
Temp. 41°C	0.43	0.80	4.90	0.43	1.18	7.67	0.03	0.03	0.03
MM	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp. 25°C	0.56	1.91	8.76	1.46	1.58	7.17	0.25	0.37	0.77
Temp. 32°C	1.02	1.82	5.37	0.96	2.98	5.90	0.62	1.02	2.71
Temp. 41°C	2.99	7.43	18.50	2.48	6.41	17.93	0.19	1.54	5.98
DMS	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp. 25°C	0.09	0.12	0.49	0.06	0.09	0.27	0.03	0.06	0.12
Temp. 32°C	0.09	0.09	0.19	0.09	0.22	0.25	0.06	0.09	0.19
Temp. 41°C	0.34	0.40	0.93	0.25	0.40	0.77	0.06	0.09	0.25
OCS	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp. 25°C	3.39	4.35	12.24	3.62	4.96	12.40	0.93	3.39	10.14
Temp. 32°C	4.35	12.21	7.80	5.80	9.83	16.66	4.50	7.80	6.63
Temp. 41°C	6.35	16.59	41.75	5.06	13.77	36.60	4.78	7.86	14.12
EM	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp. 25°C	0.15	0.37	1.05	0.19	0.37	1.16	0.12	0.15	0.49
Temp. 32°C	0.19	0.56	1.76	0.25	0.70	1.60	0.15	0.25	0.46
Temp. 41°C	0.65	1.51	3.92	0.61	1.02	2.67	0.19	0.37	0.43
SO_2	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp. 25°C	4.04	22.32	12.89	7.95	43.64	36.40	4.29	4.90	8.20
Temp. 32°C	46.22	148.53	40.52	49.42	70.73	36.03	6.85	26.36	25.41
Temp. 41°C	223.61	360.57	230.97	175.90	299.37	305.49	3.36	21.03	8.66

[1]*Source*: LBNL, 2011 and GA Tech, 2013 (Table 10); [2]C-9673 was the highest H_2S-emitting sample in LBNL 2009 emission testing and approximately equal to the highest-emitting sample in LBNL 2010 testing; [3]Average of four highest-emitting samples manufactured in China: C3, 4, 16, and 17; [4] North America (NA). H_2S—hydrogen sulfide; CS_2—carbon disulfide; MM—methyl mercaptan; DMS—dimethyl sulfide; OCS—carbonyl sulfide; EM—ethyl mercaptan; and SO_2—sulfur dioxide; RH—relative humidity.

Table 7. Estimated (empirical model) hydrogen sulfide (H_2S) concentrations as a function of temperature and humidity used in 2010 LBNL chamber studies[1]			
	H_2S Concentration (µg/m^3)		
Sample C3—7339	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp = 25°C	16.31	25.65	24.79
Temp = 32°C	23.65	43.32	51.89
Temp = 41°C	47.61	78.69	103.20
Sample C4—8357	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp = 25°C	7.18	11.32	76.68
Temp = 32°C	28.18	42.33	82.17
Temp = 41°C	52.79	88.43	154.60
Sample C16—9672	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp = 25°C	11.69	17.02	31.11
Temp = 32°C	16.77	22.91	63.98
Temp = 41°C	46.84	81.49	133.94
Sample C17—9673	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp = 25°C	1.91	25.47	54.02
Temp = 32°C	31.57	51.92	54.64
Temp = 41°C	82.91	156.82	166.81
C-Average[2]	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp = 25°C	9.27	19.86	46.65
Temp = 32°C	25.04	40.12	63.17
Temp = 41°C	57.54	101.36	139.64
Sample NA4—8037[3]	**RH 3.4%**	**RH 49%**	**RH 87%**
Temp = 25°C	3.61	8.11	5.43
Temp = 32°C	2.16	15.36	18.22
Temp = 41°C	6.23	14.71	36.11

[1]*Source*: LBNL, 2011 and GA Tech, 2013 (Table 11); [2]Average of four highest-emitting samples manufactured in China: C3, 4, 16, and 17; [3] North America (NA). H_2S—hydrogen sulfide; RH—relative humidity.

Discussion—Indoor Air Concentration Results

Effect of time, temperature, and humidity on estimated contaminant concentrations

Estimated hydrogen sulfide (H_2S) levels decreased more than 90% between 2009 and 2010 for the 2005-2006 drywall samples from China. Sulfur dioxide (SO_2) and carbon disulfide exhibited similar trends (Tables 3 and 4). The remaining sulfur compound levels appear to have remained relatively constant. The data show higher contaminant levels in drywall from China compared to those manufactured in North America among the limited number of samples tested.

LBNL studies showed substantial emission rate decays over a 1-year period for drywall manufactured in China in 2005 and 2006 [LBNL, 2010; LBNL, 2011]. This suggests that higher indoor emission rates would have been found if these samples were tested earlier. Studies have shown decreases in emission rates of some volatile contaminants in household building materials during the first year or two after installation [Park, 2006; Hodgson, 2004].

As expected, most of the estimated contaminant concentrations increased with increasing temperature and humidity (Tables 6 and 7). Emission rates were most affected by temperature. In addition to RSC emission rate testing, LBNL derived regression models to estimate the effect of temperature and humidity on emission rates [LBNL, 2011]. The regression results predict that for every 10°C rise in temperature, the H_2S emission rate will approximately double. Doubling the worst case H_2S concentration estimated by GA Tech (Table 3, C-17-9673, 658 µg/m^3 at 25°C, 50% RH) yielded an estimated concentration of 1,316 µg/m^3 (35°C, 50% RH).

Laboratory vs. Typical Home Conditions

Table 8 displays the temperature and humidity conditions during the LBNL testing as well as the mean and range of these variables in two different drywall studies where in-house data were collected. Except for the highest temperature (41°C or 105.8°F) in LBNL test conditions, others are within the range of those measured in actual homes. It is highly unlikely that indoor temperatures would reach 41°C; however, temperatures may have approached this value in the summer in a home with no air conditioning. Air conditioner failure due to copper corrosion was not uncommon in homes containing problem drywall. Except for the lowest RH value (3.4%), humidity conditions during LBNL testing were within the range of those measured in homes.

Table 8. Comparison of Temperature and Humidity Conditions in Laboratory and Typical Residential Settings

	LBNL 2009 and 2010 testing[1]	Residential[2]
Temperature (°C)	25, 32, 41	20.8 – 31.2 (mean 25.4)
Relative Humidity (%)	3.4, 49/50, 87	40 – 80 (mean 60)

[1]*Source*: LBNL, 2010 and LBNL, 2011; [2]*Source*: EHHE, 2010 and CPSC, 2009 "Tab C."

Copper Corrosion

Moderate copper corrosion occurs in atmospheres with reactive sulfur compound concentrations at and above 14 µg/m^3. Exposure to H_2S can result in corrosion to sensitive electronics at 4 µg/m^3; severe corrosion occurs at 70 µg/m^3 [NDEQ, 1997]. GA Tech RSC modeling results of 2005-2006 and some 2009 samples from China support the extent of severe metal corrosion observed in homes.

Data Limitations

These results represent only a small sample of drywall manufactured during the time periods in question and, therefore, do not represent the range of possible reactive sulfur compound and SO_2 concentrations.

The following limitations of the drywall samples tested and estimated indoor contaminant concentrations must be considered when interpreting the results:

- The small number and type of drywall samples tested are likely not representative of all drywall manufactured;
    - The drywall analyzed only include samples manufactured in 2005, 2006, and 2009. ATSDR did not estimate indoor contaminant concentrations for drywall manufactured in other years.
    - Some homes contain drywall from China manufactured in different years and possibly by different manufacturers.

    - Some homes have a mix of drywall manufactured in China and North America. The estimated indoor air concentrations were based on the assumption that only one kind of drywall was used.
- The samples tested from China that were manufactured in 2005 and 2006 very likely had higher emissions prior to LBNL analysis in 2009. Because data from earlier years are unavailable, it is impossible to determine how much higher the emissions would have been.
- Details about the warehouse storage conditions (temperature, humidity, etc.) of each drywall sample are not well documented. Emission rates may have been lower during storage compared to being installed in a building where more exposed surface area was available for contaminant off gassing. Alternatively, contaminant emission rates could have been higher from drywall stored in warehouses with high temperature and humidity than the same drywall installed in an air-conditioned home.
- Contaminant concentration estimates represent only a "snapshot in time" because variables such as emission source degradation rates, chemical reactions between these sulfur compounds, contaminant indoor half-life, and deposition rates of contaminants onto surfaces (or sinks) in the home were not available and could not have been incorporated in the analyses.

Discussion—Health Evaluation

In this section, ATSDR compares contaminant concentrations to conservative health-based screening values. If contaminant concentrations exceeded the conservative health-based screening values, the contaminant concentrations are compared to those reported in human and animal studies to determine if exposures were at levels that might cause adverse health effects.

Reduced sulfur compounds (RSCs) include hydrogen sulfide (H_2S), carbon disulfide, methyl mercaptan, dimethyl sulfide, and ethyl mercaptan. The sum of these contaminant concentrations is referred to as total RSCs (TRSCs). Their separate and combined toxicities may be generally similar to those of H_2S alone. In this health evaluation, when ATSDR describes the toxicology of H_2S it applies to TRSC as well. Sulfur dioxide (SO_2) is not an RSC. It is an oxidized sulfur compound, and its toxicological mechanisms are different than RSCs.

Selecting Contaminants for Further Evaluation

Non-cancer

Comparison Values (CVs) are non-cancer contaminant concentration guidelines with uncertainty factors applied to ensure that they are below levels of health concern. If a chemical concentration exceeds its CV, it does not mean adverse health effects will occur. It means further assessment is warranted. The assessment includes estimating an individual's contaminant dose (amount inhaled), comparing the dose to the scientific literature, and determining if exposures are at levels of health concern. ATSDR Minimal Risk Levels (MRLs) and EPA Reference Concentrations (RfCs) are used when available.[3] If MRLs or RfCs are not available, CVs developed by state health or environmental agencies, other federal agencies, and information from the available literature might be used to screen the data.

[3] An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure, even for sensitive populations. MRLs are derived for acute (1-14 days), intermediate (14-364 days), and chronic (365 days and longer) exposure durations. RfCs are estimates (with uncertainty spanning perhaps an order of magnitude) of an individual's daily inhalation exposure (including

For example, no MRL or RfC exists for methyl mercaptan, so the Texas Commission of Environmental Quality's Toxicology Division Effects Screening Level (ESL) was used. ESLs are regulatory standards developed for air permitting and used to evaluate the potential for effects to occur from exposure to airborne contaminants. ELSs are based on data concerning health effects, odor/nuisance potential, and effects on vegetation. Like MRLs, if measured airborne levels of a constituent are below the ESL, adverse health effects are not expected. If an ESL is exceeded, it does not indicate a health problem; a more in-depth review is conducted.

A hazard quotient (HQ) is the comparison of an estimated chemical intake (dose) to a CV. An HQ is calculated by dividing the estimated chemical dose by its CV. An HQ of one or below means non-cancer adverse health effects are unlikely. If a HQ exceeds one, a more in-depth review is conducted. The HQ cannot be translated to a probability that adverse health effects will occur, and it is unlikely to be proportional to risk.

Cancer

The carcinogenicity of the sulfur compounds was not evaluated for the following reasons:

- Inadequate data are available;
- No evidence of carcinogenicity has been observed in limited epidemiological studies; and,
- Long-term studies on carcinogenicity in experimental animals have not been reported.

Individual Contaminant—Screening Results

Appendix 1 displays the comparison values for each contaminant and the scientific basis. It also presents odor thresholds for these contaminants. Appendix 2 compares the estimated drywall contaminant concentrations to each compound's acute and chronic CV (when available) and the resulting HQ. Except for carbon disulfide and dimethyl sulfide, all other RSCs and $S0_2$ exceeded their respective CVs in at least one drywall sample.

Hydrogen Sulfide

A summary of which H_2S CVs were exceeded and the HQ—by drywall type/ manufacture date, year tested, and temperature and RH test conditions—is provided in Table 9 and Figures 1 and 2.

- 2009 LBNL Test Results: Estimated H_2S concentrations from the highest-emitting drywall samples manufactured in China (2005-2006) exceeded acute CVs for H_2S. All samples from China exceeded chronic CVs.[4] Acute and chronic HQ values range from 3-7 and 137-329, respectively. The 2005-2006 and 2009-manufactured samples from China exceeded intermediate CVs as well; the highest HQ was 24. H_2S was not identified in the North American sample 2009 test results.
- 2010 LBNL Test Results: Under 25^{o}C and 50% RH test conditions, chronic CVs were exceeded in both the samples made in China (2005-2006) and the sample made in North America.

Under worst-case temperature and % RH test conditions, estimated H_2S concentrations exceeded acute, intermediate, and chronic CVs in the samples made in China (2005-2006), and the chronic CV in the North American sample.

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sensitive subgroups) likely to be without an appreciable risk of deleterious effects during a lifetime. RfCs are derived from - No Adverse Effect Levels (NOAELs), Lowest Observed Effect Levels (LOAELs), or Benchmark Doses (BMDs), and include - uncertainty factors to reflect limitations of the data used. -

[4] Appendices 1 and 2 display CVs and HQs discussed in this section. -

As shown in Table 9, HQs are highest for the drywall samples manufactured in China between 2005 and 2006 ("C 2005-2006") and tested in 2009. For these samples, the chronic HQ was approximately 25 times lower (329/13) after a 1-year time frame (2009 to 2010). Note the changes in CV exceedences and HQ magnitude according to test date, drywall manufacture date and origin, and the temperature and humidity test conditions.

Table 9. H_2S Comparison Value (CV) exceedences and Hazard Quotient (HQ) by drywall type/manufacture date, year tested, and temperature and RH conditions during testing

Drywall Type	H_2S CV Exceeded (Max HQ)		
	2009 Test Results 25°C / 50% RH	2010 Test Results 25°C / 50% RH	2010 Test Results —Worst Case 41°C / 87% RH
C 2005-2006 Highest emitters	Acute[1] (7) Intermediate[2] (24) Chronic[3] (329)	Chronic (13)	Acute (2) Intermediate (6) Chronic (84)
C 2009	Chronic (15)	N/A[4]	N/A
NA 2009	None	Chronic (4)	Chronic (6)

[1]Up to 2 weeks; [2]Between 2 weeks and 1 year; [3]More than 1 year; [4]Not available (samples from China manufactured in 2009 were not analyzed by LBNL in 2010).

Other Reduced Sulfur Compounds

Although detected, the estimated carbon disulfide and dimethyl sulfide concentrations did not exceed their CVs and, therefore, are below levels of health concern. Carbonyl sulfide exceeded a chronic CV but was not likely of concern because HQs were 5 or less under worst-case conditions and 1 or less under typical exposure conditions. HQ values estimated for typical exposure conditions were similar in drywall manufactured in China and North America. The interim revised TCEQ ESL uncertainty factor of 3,000 for carbonyl sulfide reflects the incompleteness of the database, especially the sparseness of human data [TCEQ, 2008]. The estimated TRSC concentration CVs mirrored those of H_2S. Appendix 2 provides more detailed results for TRSCs.

Sulfur Dioxide

Based on LBNL 2009 sample analysis, the highest-emitting samples from China manufactured in 2005-2006 exceed acute SO_2 CVs (HQs from 10-15), as did the average of all 2005-2006 samples (HQ=6). The two highest samples analyzed in 2010 under worst-case temperature and humidity conditions had HQs of 9 and 5. The North American SO_2 HQs were not available from the 2009 analysis. The SO_2 HQ calculated from LBNL 2010 analysis was the same (2) for samples made in North America and China, which were not of health concern.

Individual Contaminants—Health Effects Evaluation

Hydrogen Sulfide

Hazard quotient results clearly show H_2S as the primary RSC of concern. Therefore, an evaluation of potential RSC health effects was performed on the basis of H_2S toxicity. Table 10 summarizes the populations at increased risk based on length of exposure, the drywall samples' origin, manufacture date, and the laboratory temperature and RH test conditions. People with asthma or asthma-like conditions are identified as the "sensitive population." The general population includes all individuals.

Acute exposure to the estimated levels of H_2S from the Chinese drywall samples could result in effects seen in clinical and epidemiological studies—most notably exacerbation of pre-existing respiratory conditions, eye and nasal irritation, and nasal tract lesions. There is some indication that changes in

vision might occur from exposure to the concentrations predicted. Although less is known about longer-term low-level exposure, health effects such as fatigue and weakness are possible.

Table 10. Populations at increased risk for health effects from H_2S exposure—by drywall type/manufacture date, year tested, and temperature and RH conditions during testing[1]

Drywall Type	2009 Test Results 25 °C / 50% RH			2010 Test Results 25 °C / 50% RH			2010 Worst Case Results 41 °C / 87% RH		
	Population at Potential Risk by Exposure Duration								
	Acute[2]	Intermed[3]	Chronic[4]	Acute	Intermed	Chronic	Acute	Intermed	Chronic
C 2005-2006, Highest emitters	All	All	All	None	None	All	Sensitive[5]	Sensitive	All
C 2009	None	None	All	N/A			N/A		
NA 2009	None	None	None	None	None	None	None	None	None

[1]Risks were determined based on the maximum estimated H_2S concentrations displayed in Tables 3, 4, and 7, [2]Up to 2 weeks, [3] Between 2 weeks and 1 year, [4]More than 1 year, [4] Not available (samples from China manufactured in 2009 were not analyzed by LBNL in 2010), [5] Those with asthma or asthma-like conditions

The ATSDR acute MRL is based on a clinical lung function investigation of three adult male and seven female asthmatics exposed to 2,800 µg/m^3 H_2S for 30 minutes [Jappinen, 1990]. These were not severe asthmatics. Although no statistically significant changes were found, changes in airway resistance were measured in two participants. This finding suggests bronchial obstruction. In addition, three of the 10 subjects complained of headaches after the exposure period ended. ATSDR applied a nine-fold uncertainty factor to reach the 98 µg/m^3 MRL (3 for use of a Minimal LOAEL, 3 for human variability, and 3 for database inadequacy). Supporting studies are included in Attachment 3.

Olfactory neuron loss was identified by ATSDR as the critical, sub-chronic (6 hours a day, 7 days a week for 10 weeks) effect from H_2S exposure. This study was the basis for the minimal risk level (MRL) for intermediate exposures from 2 weeks to 1 year [ATSDR, 2006; ATSDR, 2012] as well as the EPA RfC. Both nasal tract lesions and neurologic effects occur in the same concentration range at relatively low levels of H_2S exposure (≈ 3 - 28 mg/m^3). Neurologic effects were termed "possible indicators" (alterations in Purkinje neurons) observed during perinatal and postnatal rat exposures.

No chronic MRL has been derived. Chronic low level H_2S exposure studies have not been conducted in animals, and epidemiological exposure studies are limited. Continuous exposures have not been characterized. Previous reviews have stated that H_2S is not likely a cumulative poison due to its rapid oxidation and excretion, although there is no consensus [Khan, 1990; Savolainen, et al., 1980].

Other Reduced Sulfur Compounds

A review of effect levels from exposure to estimated levels of the other individual RSCs (carbon disulfide, methyl mercaptan, dimethyl sulfide, carbonyl sulfide, and ethyl mercaptan) suggests that modeled exposure levels were below those of health concern. Most health effect levels in humans resulted from short-term exposure in clinical tests, occupational exposures, or case studies. Effect levels in animals were determined in acute and sub-chronic studies as no chronic studies in animals have been conducted. See Appendix C for additional information. But because RSCs have some of the same target organs, exposure to this mixture of compounds exacerbates the adverse effects of exposure to H_2S alone. Additional discussion of RSC mixtures is located in the Chemical Mixtures—Health Effects section.

Figure 3 provides a visual summary of estimated indoor air H_2S and TRSC concentrations in relationship to comparison values and health effects seen in human and animal studies.

Sulfur Dioxide

People with asthma, children, and older adults (65+ years) have been identified as groups susceptible to the health problems associated with breathing SO_2 [EPA, 2010a]. Clinical investigations and epidemiological studies have provided strong evidence of a causal relationship between SO_2 and respiratory morbidity in people with asthma, and more limited epidemiological studies have consistently reported that children and older adults may be at increased risk for SO_2-associated adverse respiratory effects [EPA, 2010b; EPA, 2009].

Table 11 summarizes the health effects by exposure concentration and study conditions. Although HQs were as high as 15, the highest estimated SO_2 concentration, 397 µg/m^3, from drywall emissions was below those shown in clinical studies resulting in adverse effects in exercising asthmatics [Horstmann 1986; Boushey, 1985]. The lowest level where asymptomatic effects were measured was 520 µg/m^3 (e.g., mild constriction of bronchial passages). Sheppard et al. [1981] measured asymptomatic effects (bronchoconstriction) in exercising asthmatics exposed to 260 µg/m^3 SO_2 by mouth only. However, because nasal breathing acts as a scrubber or filter and reduces the amount of SO_2 that enters the lungs, potential health effects are uncertain in sensitive populations' breathing levels below 520 µg/m^3.

Note that asthmatic participants in the studies summarized in Table 11 had mild to moderate asthma. There is considerable uncertainty about concentrations that will affect severe asthmatics. In addition, low temperatures and humidity have been reportedly induced effects at lower SO_2 concentrations.

Table 11. Short-term sulfur dioxide (SO_2) levels associated health effects measured in clinical studies

Concentration (µg/m^3)	Population	Comment	Exposure conditions
>2,600[1]	General	Lowest effect in non-sensitive populations	Oronasal[8]
>1,560[1]	Exercising asthmatics	May require taking medication, stopping exercise, or seeking medical attention	Oronasal
1,040-1,560[1]	Exercising asthmatics	Symptoms begin (cough, wheeze, chest tightness)	Oronasal
520-650[2,3]	Exercising asthmatics	Lowest asymptomatic effects begin (bronchoconstriction)	Oronasal
650[4]	Exercising asthmatics	Effects from exercise alone, no SO_2 exposure	Oronasal
260[5]	Exercising asthmatics	Lowest asymptomatic effects using mouthpiece	Oral only[9]
26[6]	All	Acute MRL[7]	Oronasal

[1]EPA, 2008; [2]Horstmann et al., 1986; [3] Boushey et al., 1985; [4]Horstmann et al., 1988; [5] Sheppard et al., 1981; [6]ATSDR 1998; [7]ATSDR acute (up to 2 weeks) Minimal Risk Level; [8]free-breathing (nose and mouth); [9]mouth only.

All SO_2 estimates from the drywall samples were below a level believed to result in adverse effects (520 µg/m^3) [Horstmann, 1986; Boushey, 1985]. However, clinical investigations have limitations in that participants in those peer-reviewed clinical investigations were healthy and were usually mild to moderate asthmatics. These investigations have not included participants such as those with severe asthma, children, or the elderly. As discussed in the next section, exposure to the estimated $S0_2$ concentrations may add to the respiratory and irritation effects from exposure to TRSCs.

Chemical Mixtures—Health Effects Evaluation

Exposure to multiple sulfur compounds emitted from drywall may be evaluated by considering the chemicals as a mixture of total reduced sulfur compounds (TRSCs) or using a surrogate for the mixture, such as H_2S [NDEQ, 1997]. The following epidemiological studies describing exposure to TRSCs support using H_2S as a surrogate for the similar effects of TRSCs. The self-reported health effects from exposure to the mixture of TRSCs suggest exacerbation of effects compared to H_2S alone, although effects may be due to sparsely documented peak exposures. The addition of SO_2 to the TRSC mixture suggests SO_2 may potentially exacerbate an exposure to TRSCs. While the mixtures effect is unknown, other contaminants (ozone, PM2.5) may also exacerbate co-exposures [EPA, 2008].

Several epidemiological studies around paper mills in Finland (1990-1996) evaluated human health effects to mixtures of sulfur compounds. These studies report symptoms (eye and nasal irritation, cough, headache, respiratory symptoms) associated with exposure to very low levels of sulfur compounds: less than 10 $\mu g/m^3$ annual average H_2S and less than 50 $\mu g/m^3$ daily averages for H_2S and methyl mercaptan. One study reported the maximum 1-hour TRS (TRSC) concentration of 155 $\mu g/m^3$ during a 10-month period. SO_2 concentrations were very low (1 <$\mu g/m^3$) [Partti-Pellinen, et al., 1996; Marttila, et al., 1995; Marttila, et al., 1994; Jaakkola, et al., 1990; Haahtela, et.al., 1992]. Symptoms may have been associated with exposures to short-term peak contaminant concentrations, collection of which were limited in these studies.

In the Jaakkola, Finland, study [1990], people exposed to H_2S, methyl mercaptan, and methyl sulfides while living in a community around a paper mill reported eye irritation 12 times more often than people without exposure. These effects were observed at mean annual H_2S exposures estimated at 6 $\mu g/m^3$. However, the ocular symptoms that were reported may have been due to exposure to peak concentrations of H_2S (daily peaks as high as 100 $\mu g/m^3$) and not annual mean concentrations, or may have been due to co-exposure to methyl mercaptan and methyl sulfides. Methyl mercaptan is also an eye irritant [NIOSH, 2010] and was also present at an annual mean concentration of 2–5 $\mu g/m^3$ with the highest daily average concentration being 50 $\mu g/m^3$ [Jaakkola et al., 1990].

All of the South Karelia, Finland, air pollution studies found increases in the incidence of headaches or migraines in polluted communities when compared to nonpolluted communities [Jaakkola et al., 1990; Marttila et al., 1994b, 1995; Partti-Pellinen et al., 1996]; however, only in the most recent study did this finding achieve statistical significance. Using a cross-sectional, self-administered questionnaire, Partti-Pellinen et al. [1996] evaluated the increased risk of headache or migraine in adults in a slightly polluted and a reference community. In the polluted community, the mean annual TRSC concentrations were 2–3 $\mu g/m^3$, the 24-hour concentrations varied between 0 and 56 $\mu g/m^3$, and the maximum 1-hour concentration was 155 $\mu g/m^3$; there were no TRSCs detected in the reference community. In the polluted community, the SO_2 annual mean concentration was 1 $\mu g/m^3$, the 24-hour concentrations varied between 0 and 24 $\mu g/m^3$; the maximum 1-hour concentration was 152 $\mu g/m^3$. In the reference community, the mean SO_2 level was 1 $\mu g/m^3$; the maximum 1-hour concentration was 30 $\mu g/m^3$. The residents of the polluted community showed a significantly increased risk of headache both during the previous 4-week period (OR=1.83; 95% CI=1.06–3.15) and the preceding 12 months (OR=1.70; 95% CI=1.01–2.64), when compared to the residents of the reference community, even after adjusting for differences in age, sex, smoking, history of allergic diseases, education, and marital status between the two communities.

Other Considerations

Odors and Quality of Life

According to the World Health Organization (WHO), health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity [WHO, 1948]. While the direct health effect of odors on health is difficult to measure, research has shown that exposure to noxious odors such as RSCs adversely affects quality of life.

Findings from Heaney, et al. [2011] suggest that H_2S and other malodorous gases can trigger irritant and physical symptoms. Odor was strongly associated with reports of alteration of daily activities (odds ratio (OR) 9.0; 95% CI: 3.5, 23.5), negative mood states (OR 5.2; 95% CI: 2.8, 9.6), mucosal irritation (OR 3.7; 95% CI 2.0, 7.1) and upper respiratory symptoms (OR 3.9; 95% CI: 2.2, 7.0), but not positive mood states (OR 0.6; 95% CI: 0.2, 1.5) and gastrointestinal (GI) symptoms (OR 1.0; 95% CI: 0.4, 2.6).

The odor threshold for the rotten-egg odor of H_2S varies according to the individual; the geometric mean of available literature data is 11 $\mu g/m^3$, omitting extreme points and duplicate quotations; the standard error is 2.1 [Amoore & Hautala, 1983]. To avoid odor annoyance, WHO recommends that a 30-min average ambient air H_2S concentration not exceed 7 $\mu g/m^3$ [WHO, 2003].

California state regulators established an ambient air quality standard (AAQS) for H_2S that is based on the endpoint of odor "annoyance" [Collins, 2000]. This standard-0.03 ppm (42 $\mu g/m^3$) is based on a 1-hour average. This is approximately four times the population-mean odor threshold for H_2S. This methodology assumes that, on a population-average basis, the annoyance threshold occurs at a fixed multiple of the odor threshold; at the level chosen, approximately 40% of the population is expected to be annoyed by H_2S odors.

Odor sensations occur when odorants interact with receptors in olfactory epithelium in the top of the nasal cavity. Signals from activated receptors are transmitted via the olfactory nerve to the olfactory bulb and ultimately to the brain. Odorants can also stimulate free nerve endings of four other cranial nerves, including the trigeminal and vagus nerves, to induce sensations of irritation. The same compound can generate sensations of both odor and irritation, but the concentration necessary to illicit irritation is generally higher than that needed for odor with biological sulfur gases.

Two types of nerve fibers in the trigeminal nerve conduct afferent pulses: finely myelinated A-delta fibers and un-myelinated C fibers. Vasculature in the cranium is supplied by substance P-containing C fibers of the trigeminal nerve (Substance P is a neurotransmitter associated with pain and vasodilation). Thus inhaled irritants may induce headaches and migraines by increasing cortical blood flow via the trigeminovascular system. There is a temporal disparity between odor and irritant sensations with odor sensations tending to precede the irritant sensations, due in part because the agent must migrate through the mucosa to activate free nerve endings of the trigeminal nerve [Schiffman, et. al., 2000; Shusterman,1992].

The odor thresholds of sulfur compounds emitted from problem drywall are displayed in Appendix 1. Table 12 displays the contaminants whose estimated concentrations reached or exceeded their odor threshold. The estimated concentrations of H_2S and methyl mercaptan exceeded odor threshold in some drywall samples from China. Therefore, physical symptoms such as headache and fatigue can occur and adversely affect the quality of life for those exposed.

Table 12. Sulfur compounds at or above odor threshold by drywall type/manufacture date, year tested, and temperature and humidity conditions during testing

Drywall Type	2009 Test Results 25°C / 50% RH ≥ Odor Threshold	2010 Test Results 25°C / 50% RH ≥ Odor Threshold	2010 Test Results —Worst Case 41°C / 87% RH ≥ Odor Threshold
C 2005-2006 Ave- 4 highest emitters	H_2S, methyl mercaptan	H_2S, methyl mercaptan	H_2S, methyl mercaptan, ethyl mercaptan
C 2009 Ave[1]	H_2S	N/A[2]	N/A
NA 2009	NI[3]	None	None

[1]Average of all nine samples from China manufactured between 2009; [2]Not available (samples from China manufactured in 2009 were not analyzed by LBNL in 2010); [3]Not identified in LBNL analysis; RH—relative humidity.

Sensitive populations

People with asthma are a sensitive population to airborne irritants. Exposure to irritant gases exacerbates asthma symptoms. Epithelial damage and epithelial shedding occur in the airway passages in asthma and other respiratory disorders. Nerve endings are exposed by epithelial shedding, allowing irritant gases access to free nerve endings, aggravating asthma and allergies [Schiffman, et al., 2000]. Preliminary results using nasal computational fluid dynamics modeling suggested that differences in nasal anatomy and ventilation among adults and children do not significantly affect the H_2S tissue dose in the olfactory region [Schroeter, et al., 2010].

From an exposure perspective, children may be more susceptible to TRSCs than are adults. Compared to adults, their breathing rate is higher and they are shorter in stature (RSCs and SO_2 are heavier than air so their concentrations may be higher closer to the ground). ATSDR [Campagna et al., 2004] examined the possible relationship between ambient levels of TRSC and hospital visits among residents of Dakota City and South Sioux City, Nebraska. Air monitoring data showed H_2S as the primary constituent of the TRSC in the area. The primary sources were a beef slaughter facility and a leather tanning facility. Among children under 18 years of age, positive associations were found between unplanned hospital visits for asthma and the high H_2S and/or TRSC levels on the previous day. The same positive association was not found for adults. A high TRSC or H_2S level was defined as a 30-minute rolling average of ≥30 ppb (42 $\mu g/m^3$).

Conclusions -

People who were exposed to hydrogen sulfide and other sulfur compounds emitted by some drywall manufactured in China may have experienced adverse health effects or a reduced quality of life. The available data cannot be used to determine if people are still being exposed to levels that could cause health effects or adversely affect quality of life.

1. - For the drywall samples manufactured in China between 2005 and 2006
    - Based on the limited number of drywall samples tested, exposures to the estimated levels of hydrogen sulfide and sulfur dioxide from drywall samples manufactured in China between 2005 and 2006 were a public health concern. Short-term exposures might result in effects seen in both clinical and human epidemiologic studies. These effects include exacerbation of pre-existing respiratory conditions, eye and nasal irritation, headache, changes in vision, and weakness. Although less certain, longer-term exposures may have increased the risk of damage to nasal tissue. Exposure to estimated contaminant concentrations could diminish a resident's quality of life by triggering irritant (eye, nose, and throat) and physical (respiratory, gastrointestinal) symptoms, leading to negative mood states, and altering daily activities.
    - The estimated contaminant concentrations increased with increasing temperature and - humidity. -
    - Given the more than 90% reduction in hydrogen sulfide emission rates between the 2009 and 2010 laboratory testing, estimated contaminant concentrations from drywall samples were likely higher closer to their 2005-2006 date of manufacture.
    - Estimated contaminant concentrations from the drywall samples tested are consistent with levels resulting in the severe metal corrosion observed in homes.

2. - For the drywall samples manufactured in China in 2009
    - Based on the limited number of drywall samples tested, long-term exposures to the estimated levels of hydrogen sulfide from drywall samples manufactured in China in 2009 may have posed a public health concern for sensitive individuals (e.g., those with asthma).

3. - For the drywall samples manufactured in China in 2005, 2006, and 2009
    - Current contaminant levels cannot be estimated with the data available for the drywall samples manufactured in China in 2005, 2006, and 2009. Therefore, the potential hazard, if any, from current exposures cannot be assessed based on the 2009-2010 laboratory data.

4. - For the drywall samples manufactured in North America in 2009
    - Based on the limited number of drywall samples tested, exposures to the estimated contaminant levels from drywall samples manufactured in North America in 2009 were below levels of public health concern. These samples were not identified by CPSC as problem drywall.

NOTE: Because of the small number of drywall samples tested, these conclusions do not represent the range of all possible sulfur compound concentrations and should not be generalized to all drywall manufactured during the period of concern.

Recommendations

1. ATSDR recommends that people with health symptoms or health effects they feel are associated with living in a home with problem drywall provide this ATSDR health consultation report to their health care provider.

2. ATSDR recommends that residents in homes with drywall that meet the CPSC problem drywall "case definition" follow the CPSC/U.S. Department of Housing and Urban Development (HUD) remediation guidance. This guidance is available at: http://www.cpsc.gov/en/safety-education/safety-education-centers/drywall-information-center/.

Additional Resources

ATSDR is working with the Pediatric Environmental Health Specialty Units (PEHSUs) and the Association of Occupational Environmental Clinics to provide updated guidance to health care providers and the public.

This health consultation, the updated PEHSU guidance, the GA Tech modeling reports, and other problem drywall resources will be available on the ATSDR drywall Web site (http://www.atsdr.cdc.gov/drywall/).

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Appendices -

Appendix 1. Comparison Values (CVs) and Odor Thresholds for RSCs and SO_2

Contaminant	Odor Thresholds µg/m³	Acute Health-based CV µg/m³	Chronic Health-based CV µg/m³	CV Description Acute/Chronic
Hydrogen sulfide	11[1]	98[2]	2[3]	ATSDR acute MRL/EPA Reference Concentration
Carbon disulfide	50[4]	30[5]	3[5]	TCEQ ESL short-term health, 2003/TCEQ ESL long-term health, 2003
Methyl mercaptan	2[5]	10[6]	1[5]	ERPG-1/TCEQ health-based ESL, 2012
Dimethyl sulfide	7.6[5]	1,300[6]	25[5]	ERPG-1/TCEQ health-based ESL, 2011
Carbonyl sulfide	135[7]	4,500[5]	9[5]	TCEQ health-based ESL(ReV), 2012/TCEQ health-based ESL (ReV), 2012
Ethyl mercaptan	0.8[5]	2,500[8]	1.3[5]	8-hr AEGL-1/TCEQ health-based ESL, 2012
Total Reduced Sulfur Compounds	NA	98[2]	2[3]	Same CVs as hydrogen sulfide
Sulfur dioxide	1,175[9]	26[9]	NA	ATSDR acute MRL/NA

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NA – not available. No appropriate residential exposure health-based comparison value was located for these contaminants.

An ATSDR Minimal Risk Level (MRL) is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. They are derived for acute (1-14 days), intermediate (>14-364 days), and chronic (365 days and longer) exposure durations.

EPA Reference Concentration (RfC). RfCs are estimates (with uncertainty spanning perhaps an order of magnitude) of an individual's daily inhalation exposure (including sensitive subgroups) likely to be without an appreciable risk of deleterious effects during a lifetime.

Effects Screening Levels (ESLs) are currently used by the TCEQ Toxicology Division for air permitting. ESLs, expressed in terms of microgram per cubic meter ($\mu g/m^3$) or parts per billion by volume (ppbv) in air are used to evaluate potential for effects to occur as a result of exposure to concentrations of constituents in the air. ESLs are based on data concerning health effects, odor/nuisance potential, and effects on vegetation. They are not ambient air standards. If predicted or measured airborne levels of a constituent do not exceed the screening level, adverse health or welfare would not be expected to result. If ambient levels of constituents in air exceed the screening level, it does not necessarily indicate a problem, but a more in-depth review is conducted. Short-term indicates a 1-hour average, unless otherwise noted. Long-term denotes an annual average. A reference value (ReV) is based on adverse health effects and is often used to derive an ESL by multiplying the ReV with an HQ of 0.3 to account for multiple chemical exposures.

ERPG-1 –The Emergency Response Planning Guideline (ERPG) is the maximum concentration in air below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

AEGL-1 – The Acute Emergency Guideline Level (AEGL) is the airborne concentration of a substance 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.

Appendix 2. Screening Level Comparison—Comparison Values (CVs) and Hazard Quotients (HQs)

Comparison Values

Chemical[1]	hydrogen sulfide	carbon disulfide	methyl mercaptan	dimethyl sulfide	carbonyl sulfide	ethyl mercaptan	TRSC[3]	sulfur dioxide
CV[2] acute	98	30	10	1,300	4500	2,500	98	26
CV intermediate	28						28	
CV chronic	2	3	1	25	9	1.3	2	NA

2009 Data, Room Temperature (25°C)/Relative Humidity (50%)

	hydrogen sulfide	carbon disulfide	methyl mercaptan	dimethyl sulfide	carbonyl sulfide	ethyl mercaptan	TRSC	sulfur dioxide
C17 9673 highest emitter[1]	658	2	5	0.2	27	0.3	693	314
HQ acute	7						7	12
HQ Intermediate	24						25	
HQ chronic	329		5		3		347	
C4 8357 second highest emitter[1]	607	13	7	2	6	NA	635	397
HQ[4] acute	6						6	15
HQ Intermediate	22						23	
HQ chronic	304	4	7				318	
Average - 4 highest emitters[1]	472	6	5	1	15		499	265
HQ acute	5						5	10
HQ Intermediate	17						18	
HQ chronic	236	2	5		2		250	
Average - All 2009 manufacture[1]	30	0.3	1	0.1	11	0.2	43	39
HQ acute								2
HQ Intermediate	1						2	
HQ chronic	15		1		1		22	
Average - All 2005-2006 manufacture[1]	273	5	3	1	12	0.3	294	159
HQ acute	3						3	6
HQ Intermediate	10						11	
HQ chronic	137	2	1		1		144	
NA4 8037 - North America[1]		3		1				
HQ acute								
HQ Intermediate								
HQ chronic		1						

1 - all concentrations in µg/m^3 HQ ≥ 1

2 - Comparison Value

3 - Total Reduced Sulfur Compounds

4 - HQ = Hazard Quotient = Concentration/CV

Appendix 2. Screening Level Comparison—Comparison Values (CVs) and Hazard Quotients (HQs), Cont'd

Comparison Values

Chemical[1]	hydrogen sulfide	carbon disulfide	methyl mercaptan	dimethyl sulfide	carbonyl sulfide	ethyl mercaptan	TRSC[3]	sulfur dioxide
CV[2] acute	98	30	10	1,300	4500	2,500	98	26
CV intermediate	28						28	
CV chronic	2	3	1	25	9	1.3	2	NA

2010 Data, Highest Temperature (41°C)/Relative Humidity (87%)

	hydrogen sulfide	carbon disulfide	methyl mercaptan	dimethyl sulfide	carbonyl sulfide	ethyl mercaptan	TRSC	sulfur dioxide
C17 9673 highest emitter[1]	167	5	19	1	42	4	238	231
HQ[4] acute	2		2				2	9
HQ Intermediate	6						9	
HQ chronic	84	2	19		5	3	119	
Average - 4 highest emitters[1]	140	8	18	1	37	3	207	306
HQ acute	1		2				2	12
HQ Intermediate	5						7	
HQ chronic	70	3	18		4	2	104	
NA4 8037 - North America[1]	36	0.03	6	0.3	12	0.4	55	9
HQ acute								
HQ Intermediate	1						2	
HQ chronic	18		6		1	1	28	

2010 Data, Room Temperature (25°C)/Relative Humidity (50%)

	hydrogen sulfide	carbon disulfide	methyl mercaptan	dimethyl sulfide	carbonyl sulfide	ethyl mercaptan	TRSC	sulfur dioxide
C3 7339 - highest emitter[1]	26	0.5	2	0.1	5	0.3	34	41
HQ acute								2
HQ Intermediate							1	
HQ chronic	13		2				17	
Average - 4 highest emitters[1]	20	0.3	2	0.1	5	0.4	28	44
HQ acute								2
HQ Intermediate							1	
HQ chronic	10		2				14	
NA4 8037 - North America[1]	8	0.03	0.4	0.06	3	0.2	12	44
HQ acute								2
HQ Intermediate								
HQ chronic	4						6	

1 - all concentrations in µg/m^3

HQ ≥ 1

2 - Comparison Value

3 - Total Reduced Sulfur Compounds

4 - HQ = Hazard Quotient = Concentration/CV

Appendix 3. Basis for Comparison Values and Effect Levels

Attachment 3 - Basis for Comparison Values and Effect Levels for Hydrogen Sulfide and Total Reduced Sulfur Compounds

H_2S µg/m^3 (ppb)	CVs	BASIS for CV	EXPOSURE
2 (1.4 ppb)	RfC	NOAEL 640 µg/m^3 (HECadj), olfactory neuron loss Rat,s UF 300 (Brenneman 2000).	6hr/7dy/10wk
10 (8)	REL	NOAEL 5.4 ppm HEC, 850 ppb. UF 100, inflammation of nasal mucosa mice.(CIIT 1983).	6hr/5dy/90dy
14 (10)	LOA	level of distinct odor awareness affecting 10%	
28 (20)	iMRL	NOAEL 640 ug/m3 (HECadj), olfactory neuron loss Rats, UF 30 (Brenneman 2000)	6hr/7dy/10wk
98 (70)	aMRL	LOAEL (min) 2.8 mg/m3, headache 3/10 asthmatics, 2/10 30% Raw,Sgaw. UF 3x3x3. (Jappinen 1990)	2 ppm 30 min
460 (329)	AEGL-1	8 hours. Headache asthmatics (Jappinen 1990)	2 ppm 30 min
700 (500)	TEEL-0		
1400 (1000)	TWA-ACGIH		
		Levels of Exposure	
4 (3) - 70 (50)	corrosion	(Rapaport 1988) Corrosion to sensitive electronics at 4 ug/m3, severe corrosion at 70 ug/m3	
ann mean 8 (6)	epi	(Jaakkola, 1990) Eye and nasal symptoms and cough. Highest daily avg 100 ug/m3.	12 months
2800 (2000)	min LOAEL	(Jappinen 1990) asthmatics - headache (3/10), 30% incr resistance, decr conductance (2/10)	2 ppm 30 min
2800 (2000)	NOAEL	(Bhambhani and Singh 1991) cardio, metab	30 min
7000 (5000)	LOAEL	(Bhambhani and Singh 1991) metab (incr blood lactate w/exercise)	30 min
7000 (5000)	NOAEL	(Bhambhani 1994) cardio, resp	2 ppm 30 min
7000 (5000)	LOAEL	(Bhambhani 1996) musc/skel (decr citrate synthase, exercising 50% max aerobic power)	2x30 min
14000 (10000)	NOAEL	(Brenneman 2000) Rats	6hr/7dy/10wk
14000 (10000)	NOAEL	(Bhambhani 1997) human, cardio	2x30 min
14000 (10000)	LOAEL	(Bhambhani 1997) human, metab (incr blood lactate, decrease O2 uptake	2x30 min
14000 (10000)	NOAEL	(Khan 1990) cytochrome oxidase activity decrease	4 hours
28000 (20000)	min LOAEL	(Haider 1980) G Pig. Eye irritation.	1 hr/dy/11days
42000 (30000)	LOAEL	(Brenneman 2000) Rats Olfactory neuron loss.	6hr/7dy/10wk
TRSC µg/m^3 (ppb)	**CVs**	**BASIS for CV**	**EXPOSURE**
7 (5)	CV	Nebraska 30-day rolling average standard. Based on moderate corrosion with UF of 2. For areas with RH > 60%	30 days
14 (10)	CV	Nebraska 30-day rolling average standard. Based on moderate corrosion. For areas with RH =/< 60%	30 days
14 (10)	CV	Ontario chronic exposure air quality standard.	24 hours
21 (15)	CV	acute Ontario CV	1 hour
140 (100)	ref value	(Bhambhani and Singh, 1991) increased bloood lactate levels indicative of cytochrome oxidase activity inhibition. NOAEL 2 ppm UF 20	>16 min
		Levels of Exposure	
ann mean 2-3 (1-2)	epi	(Partti-Pellinen, 1996) Self-reported. Excess cough and headache. SO2 2 ug/m3 (0.7 ppb). Max daily TRS 56 ug/m3. Peaks?	12 months
10-30 (7-21)	epi	(Marttila 1995) increased nasal and eye irritation. Daily mean 0-82; monthly mean 3-19 ug/m3.	15 months
ann mean 12 (9)	epi	(Jaakkola, 1990) Eye and nasal symptoms and cough. Highest daily avg 100 ug/m3 (H2S), 150 ug/m3 (MM).	12 months
14 (10)	corrosion	Moderate copper corrosion.	1 month
22 (16)	epi	(Killburn and Warshaw 1995) Numerous neurobehavioral complaints in former refinery workers and nearby residents. SO2 hi but not included.	
>30 (21)	epi	(Marttil 1995) increased nausea	15 months
42 (30) rolling avg	epi	(Campagna 2004) positive assoc hospital visits for children for respiratory disease (including asthma) and previous day high TRS.	30 min
daily avg > 35 (25)	epi	(Haahtela, 1992) Eye and respiratory symptoms. Self reported. 24-hour averages were 35 ug/m3 (25) and 43 ug/m3 (31). SO2 1 ug/m3.	2 days
daily avg 98 (70)	epi	(Jaakkola, 1990) Eye and nasal symptoms and cough	12 months
2800 (2000)		(Jappinen, 1990) Broncial obstruction in asthmatics	30 min
>2800 (2000)		(Bhambhani and Singh, 1991) increased bloood lactate levels indicative of cytochrome oxidase activity inhibition. Inhibited enzyme activity	30 min

Figure 1: Hazard Quotients (HQs) for Estimated Hydrogen Sulfide (H_2S) and Total Reduced Sulfur Compound (TRSC) Concentrations Compared to the EPA Reference Concentration (RfC)

Drywall Sample ID	Sample Analysis Data	Temp. (°C)/ RH (%)	Hazard Quotients		
			H_2S	EPA RfC	TRSC
C17- 9673 LBNL predicted (highest emitter with 10°C temperature increase)* 2009 data	2009	35 / 50	658		NA
C17- 9673 highest emitter, 2009	2009	25 / 50	329		347
C4-8357 second highest emitter	2009	25 / 50	304		318
				300 (NOAEL)	
Average - 4 highest emitters	2009	25 / 50	237		250
Average - all 2005-2006	2009	25 / 50	137	3 UF (Animal to Human)	144
				100	
C17-9673, highest T/RH	2010	41 / 87	84		119
Average – 4 highest emitters	2010	41 / 87	70		104
NA4 North American	2010	41 / 87	18	10 UF (Subchronic to Chronic)	28
Average all 2009 manufacture	2009	25 / 50	15		22
C3 #7339 highest emitter	2010	25 / 50	13		17
Average – 4 highest emitters	2010	25 / 50	10		14
				10	
NA4 #8037 North American	2010	25 / 50	4	10 UF (Human Variability)	6
				1 (RfC)	

* LBNL Regression analysis ((LBNL, 2011)

Figure 2: Estimated Hydrogen Sulfide (H_2S) and Total Reduced Sulfur Compound (TRSC) Concentrations Compared to ATSDR Minimal Risk Levels (MRLs) and EPA Reference Concentration (RfC)

Drywall Sample ID	Sample Analysis Data	Temp. (°C)/ RH (%)	Estimated H_2S/TRSC Concentration vs. Comparison Values (CVs), ug/m³		
			H_2S	CV	TRSC
C17-9673 LBNL predicted (highest emitter with 10° C. temperature increase)*	2009	35 / 50	1316		
C17-9673 highest emitter	2009	25 / 50	658		693
			RfC, Intermediate MRL NOAEL 640		
C4 -8357 second highest emitter	2009	25 / 50	607		635
Average – 4 highest emitters	2009	25 / 50	472	3 UF (Animal to Human)	499
Average - all CDW 2005-2006 manuf.	2009	25 / 50	273		294
				213	
C17-9673 highest emitter	2010	41 / 87	167		238
Average – 4 highest emitters	2010	41 / 87	140		207
			Acute MRL 98		
NA4-8037 North American	2010	41 / 87	36	10 UF (Subchronic to Chronic)	55
Average – all CDW 2009 manuf.	2009	25 / 50	30		43
			Intermediate MRL 28		
				21	
C3-7339 highest emitter	2010	25 / 50	26		34
Average - all CDW 2009 manuf.	2010	25 / 50	20	10 UF (Human Variability)	43
Average - 4 highest emitters	2010	25 / 50	20		28
NA-8037 North American	2010	25 / 50	8		12
				2 (RfC)	

* LBNL Regression analysis ((LBNL, 2011)

Figure 3: Estimated Hydrogen Sulfide (H_2S) and Total Reduced Sulfur Compound (TRSC) Concentrations Compared to Human and Animal Studies

Drywall Sample ID	Sample Analysis Data	Temp. (°C)/ RH (%)	Estimated H_2S/TRSC Concentration vs. Studies, ug/m³		
			H_2S	Associated Health Effect(s)	TRSC
C17- 9673 LBNL predicted (highest emitter with 10°C temperature increase) *	2009	35 / 50	1316		
C17- 9673 (highest emitter)	2009	25 / 50	658		693
EPA RfC and ATSDR Intermediate MRL - NOAEL			**640**	HECadj, rat, olfactory	
C4 – 8357 (second highest emitter)	2009	25 / 50	607		635
Average – 4 highest emitters	2009	25 / 50	472		499
Average all CDW 2005-6 manuf.	2009	25 /50	273		294
C17-9673 highest T/RH	2010	41 / 87	167		238
Average – 4 highest emitters	2010	41 / 87	140		207
		Acute MRL	**98**		
			98	Epi; daily avg.; eye, nasal effects (Jaakkola, 1990)	
NA 4, #8037 - North American	2010	41 / 87	36		55
				1-hr eye, headache, Vision, Weakness	50
				Epi; hospital visits for resp. problems (Campagna, 2004)	42
				Epi; daily avg; eye, respir (Haahtela, 1992)	35
Average – all CDW 2009 manuf.	2009	25 / 50	30		43
				Epi; nasal, eye effects (Marttila, 1995)	10-30
		Intermediate MRL	**28**		
C-3 #7339 highest emitter	2010	25 / 50	26		34
Average—4 highest emitters	2010	25 / 50	20		28
			14	Level of awareness	
				Epi; annual average mean; eye, nasal (Jaakkola, 1990)	8
NA 4, # 8037 - North American	2010	25 / 50	8		12
				Epi; annual average mean; cough, headache (Partti-Pellinen, 1996)	2-3
		EPA RfC	**2**	HECadj, rat, olfactory	

* LBNL Regression analysis ((LBNL, 2011)