SULFURYL FLUORIDE (Vikane®)

RISK CHARACTERIZATION DOCUMENT

Volume II

Exposure Assessment

Worker Health and Safety Branch
Department of Pesticide Regulation
California Environmental Protection Agency

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EXPOSURE ASSESSMENT DOCUMENT FOR PESTICIDE PRODUCTS CONTAINING SULFURYL FLUORIDE

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ABSTRACT

Sulfuryl fluoride has been used as a structural fumigant to control wood-destroying pests since 1957. In 2002, reported use of sulfuryl fluoride in California was 3,045,084 pounds. With the phase-out of methyl bromide use, sulfuryl fluoride is actively being developed as an alternative, which will likely increase its use in the future. This exposure assessment was prepared as part of the Department of Pesticide Regulation's risk assessment process mandated by California law. Due to its high vapor pressure, the expected primary route of sulfuryl fluoride exposure is through inhalation. Worker and non-worker short-term, intermediate and long-term sulfuryl fluoride exposures were estimated using sulfuryl fluoride air concentrations detected in chemical-specific studies performed at submaximal applications rates (11-16 oz/1,000 ft^3 or 11-16 g/m^3). Worker and bystander exposures resulting from applications performed at the maximal application rate may be 10-15 times greater than that listed below.

Short-term exposure from tasks performed by fumigation workers, expressed as absorbed daily dosage (mg/kg/day; 18% inhalation absorption), were estimated as follows:

- fumigant introduction, 0.029
- initial ventilation (fan placement, structure opening), 0.0001
- structure closing following first hour of aeration, 0.000006
- clearance certification, 0.009
- ground snake removal, 0.04
- ground seam opening, 0.30
- roof seam opening, 0.31
- tarpaulin folding, 0.06
- all fumigator only tasks, 0.04
- all tent crew only tasks (general detarping), 1.13
- commodity handler, 0.43

Short-term exposure of male or female residents or other individuals during the first day of reentry into cleared structures, expressed as absorbed daily dosage (mg/kg/day; 18% inhalation absorption), were estimated as follows:

- <1 year, 0.57
- 6-8 years, 0.32
- 12-14 years, 0.23
- adults, 0.24

Short-term exposure of male or female bystanders to structural (s) or nonfood commodity (c) fumigation sites, expressed as absorbed daily dosage (mg/kg/day; 18% inhalation absorption), were estimated as follows:

- <1 year, 0.90 (s); 2.3 (c)
- 6-8 years, 0.58 (s); 1.5 (c)
- 12-14 years, 0.41 (s); 1.0 (c)
- adults, 0.43 (s); 1.1 (c)

INTRODUCTION

This human exposure assessment document has been prepared as part of the risk assessment process conducted by the California Department of Pesticide Regulation (DPR) under provisions of the Birth Defect Prevention Act of 1984 (Food and Agricultural Code (FAC) Sections 13121-13135). This document presents estimates of occupational and nonoccupational exposures to the active ingredient sulfuryl fluoride and will be used as an integral part of the mitigation process if exposures are determined to pose excessive risk to human health.

This exposure assessment document contains information regarding the physical and chemical properties of sulfuryl fluoride, as well as its formulations, registered uses, exposure-associated illnesses, metabolism, patterns of use, and regulation in California. As a whole, this information was used to establish scenarios and estimates for short-term, intermediate-term, annual and lifetime exposures. Short-term exposure is defined as that exposure which may occur daily but not exceeding 7 days; short-term exposures occurring 1 day or less have been specified herein as acute. Intermediate-term exposure is that exposure lasting more than 7 days but substantially less than 1 year. Annual and lifetime exposures are defined as the average daily exposure amortized over 365 days and the annual average daily exposure amortized over one's lifetime, respectively (Andrews, 2001).

Sulfuryl fluoride is a colorless, odorless gas with the chemical formula SO_2F_2 and the chemical structure shown in Figure 1.

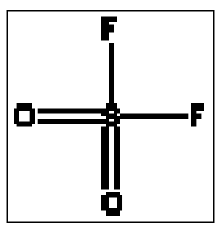


Figure 1. Chemical structure of sulfuryl fluoride.

A broad spectrum insecticide and rodenticide, sulfuryl fluoride was first introduced as a fumigant in 1957 and is currently used for the control of existing infestations of household and structural pests including drywood termites, Formosan subterranean termites, powder post beetles, death watch beetles, old house borers, bedbugs, cockroaches, clothes moths and rodents (Dow AgroSciences LLC, 2000).

Sulfuryl fluoride was first registered with the United States Environmental Protection Agency (U.S. EPA) in December 1959. As part of the reregistration of pesticides containing any active ingredient first registered before November 1, 1984, the U.S. EPA required additional product chemistry and occupational and residential exposure data for pesticides containing sulfuryl fluoride as an active ingredient in June 1985 (U.S. EPA, 1985). In September 1993, the Reregistration Eligibility Decision (RED) for pesticides containing sulfuryl fluoride as an active ingredient (U.S. EPA, 1993) was released. In summary, the U.S. EPA determined the one end-use product containing sulfuryl fluoride, Vikane (a registered trademark of Dow AgroSciences LLC), would not pose unreasonable risk or adverse effects to humans or the environment, thus making uses of this product eligible for reregistration. However, the decision noted a concern that the reentry (clearance) air concentration of 5 parts per million (ppm) sulfuryl fluoride may not be appropriate and suggested 2 ppm for adults and 1 ppm for children. Since no postfumigation data directed at the rate of sulfuryl fluoride decline from air were available to determine the appropriate reentry air level, the U.S. EPA gave the registrant 1 year to submit exposure data and data which could be used to determine the postfumigation decline rate of sulfuryl fluoride. To address the concern raised by U.S. EPA, DowElanco provided data to demonstrate the dissipation rate of sulfuryl fluoride and support the approved aeration procedures that allowed structure clearance at 5 ppm (Shurdut, 1995). The risk estimates presented by the registrant's report indicated acceptable exposures. These data were evaluated and used in the present exposure assessment to estimate upperbound and average reentry exposures for residents returning to homes. It should be noted that, in the context of this exposure assessment, the terms reentry level and clearance level are synonymous and refer to the sulfuryl fluoride air concentration at which treated areas may be certified as being safe for tenants to reoccupy their homes or for workers to reenter their worksites.

The FAC Section 12824 requires DPR to attempt to eliminate the use of any pesticide that endangers the environment in California. In addition, the Birth Defect Prevention Act of 1984 was enacted to prevent pesticide-induced abortions, birth defects, and infertility and required DPR to identify 200 pesticide ingredients with the most significant data gaps and widespread use and which were suspected to be hazardous to people. The identified ingredients were listed in Title 3 of the California Code of Regulations (3 CCR) Section 6198.5 (3 CCR 6198.5) effective June 16, 1987. Registrants of pesticide products containing any of the listed active ingredients were notified and required to fill gaps in the mandatory health effects data (reproductive effect, chronic toxicity, mutagenicity, neurotoxicity, oncogenicity, and teratogenicity) by January 15, 1992. Sulfuryl fluoride was among the active ingredients identified in this regulation and, following registrant submission of data pursuant to FAC 13127, no gaps remain in the mandatory health effects data for this compound (DPR, 1998). However, these data were directed to sulfuryl fluoride inhalation exposure and indicate potential adverse effects (neurotoxicity, chronic toxicity). Therefore, this exposure assessment has been initiated as part of DPR's risk assessment process to determine the significance of these adverse effects to human health.

Throughout this assessment, the process of measuring sulfuryl fluoride air concentration or sulfuryl fluoride level has been referred to as "monitoring," e.g., sulfuryl fluoride monitoring, sulfuryl fluoride air monitoring, monitoring sulfuryl fluoride levels, breathing zone monitoring. Also, any reference to sulfuryl fluoride level or concentration (e.g., reentry level) refers to that concentration of sulfuryl fluoride in air. Methods used to monitor or measure the amount of sulfuryl fluoride in air are presented in the

"Determination of sulfuryl fluoride air concentration" section of the EXPOSURE ASSESSMENT chapter.

FACTORS DEFINING EXPOSURE SCENARIOS

Physical and chemical properties.

The physical and chemical properties of sulfuryl fluoride (CAS NO. 2699-79-8), listed below, are useful in determining the potential routes of human exposure (U.S. EPA, 1993; Tomlin, 1994; Budavari, 1996).

Molecular weight	102.07
Physical appearance	colorless, odorless
Solubility (ml SF/100 ml solvent)	4-5 (water); 24-27 (alcohol); 210-220 (toluene)
Solubility (mg/kg water, 25˚C)	750
Boiling point (˚C)	-55.38
Melting point (˚C)	-135.82
Vapor pressure (Pa at 21.1˚C)	$1.7x10^{6}$
Specific gravity (g/L at 25˚C)	3.72
Vapor density (relative to air = 1)	3.52
Log octanol/water partition coefficient	0.41

Conversion factors:

1 ppm = 4.17 mg/m^3 at normal temperature and pressure

1 oz/1,000 ft^3 = 1 g/m^3 = 241 ppm

Sulfuryl fluoride is noncorrosive and not very reactive; it does not hydrolyze in water but is hydrolyzed by aqueous sodium hydroxide solution (Budavari, 1996). Based on its low boiling point and high vapor pressure indicated above, sulfuryl fluoride is expected to remain a gas over a wide range of ambient temperatures, thus dermal and oral exposure to surface residues are expected to be insignificant. Although no available studies address dermal absorption of sulfuryl fluoride, mucous membrane and dermal permeability are expected to be very low based upon sulfuryl fluoride's relative insolubility in water and low octanol/water partition coefficient noted above. Therefore, the route of potential sulfuryl fluoride exposure, as assessed in this document, is through inhalation.

Although dietary exposure is not part of this assessment, it should be noted that while the sorption of sulfuryl fluoride by most foods is insignificant, foods with a high fat content, such as corn oil, have demonstrated significant sorption of sulfuryl fluoride followed by a rapid desorption (Scheffrahn *et al.*, 1987a; Scheffrahn *et al.*, 1992b). Also, sulfuryl fluoride may break down into sulfate and fluoride ion upon contact with the protein fraction of foods, and thus a fluoride residue may remain in fumigated food commodities (Scheffrahn *et al.*, 1987a; Wright *et al.*, 2001).

Formulations and labeled uses

Current products

Sulfuryl fluoride is a restricted use pesticide based on its inhalation toxicity (3 CCR 6400(a); U.S. EPA, 1993); thus its sale and use is limited to certified applicators and those under their direct supervision. There is one sulfuryl fluoride product currently registered in California, Vikane, which is manufactured by Dow AgroSciences LLC (U.S. EPA Registration Number 62719-4). Vikane is a pressurized liquid/gas formulation containing 99.8% sulfuryl fluoride as the active ingredient. It is used in tarpaulin, taped, or chamber fumigation applications and approved for use in dwellings, including mobile homes, buildings, construction materials, furnishings, and vehicles, including automobiles, buses, surface ships, rail cars, and recreational vehicles, excluding aircraft (Dow AgroSciences LLC, 2000).

It is recommended to apply Vikane at temperatures greater than 40˚F and for an exposure period ranging between 2-72 hours. The Vikane dosage is dependent upon soil or slab temperature, exposure period, relative humidity, pest and egg stage to be controlled, and the half-loss time (HLT) (Dow AgroSciences LLC, 1998 and 2000). HLT is defined as the amount of time for one-half of the initial sulfuryl fluoride air concentration to be lost, and indicates how well a structure retains the gas. Table 1 provides two examples for comparison of how temperature and HLT affect the amount of Vikane to be applied (i.e., shot) in a structural fumigation for drywood termite control. The maximum Vikane application rate would target powder post or death watch beetles, ranging between 60-160 oz/1,000 ft^3 (60-160 g/m^3; ~24-hr exposure period; Fan and Walters, 2002).

Table 1. Sample application rates for a structural fumigation to control drywood termites. [a]

Structure volume	Exposure time	HLT [b]	Temperature	Application rate [a]	Vikane applied [c]
ft^3	hr	hr	˚F	Vikane lb/1000ft^3	lb
20,000	20-24	72	90	0.25	5
20,000	20-24	0.5	50	30	600

[a] Application rates are based upon Fumiguide* B for Vikane Fumigant, Dow Chemical U.S.A., Agricultural Products Department, Midland, MI. Fumiguide is a trademark of Dow Chemical Company.

[b] HLT, half-loss time, defined as the amount of time for one-half of the initial sulfuryl fluoride air concentration to be lost.

[c] Based upon the Vikane formulation, the amount of active ingredient, sulfuryl fluoride, is 99.8% of the value listed in this column.

Since Vikane is odorless and colorless, chloropicrin, a colorless liquid fumigant/warning agent with intensely irritating tear gas odor, is used as a warning agent (1 oz/10,000-15,000 ft^3 or 0.07-0.1 g/m^3 of space to be fumigated) and is introduced at least 5 to 10 minutes prior to the introduction of Vikane into the site. It should be noted that this exposure assessment is directed to sulfuryl fluoride alone. Exposure to chloropicrin will be the subject of a forthcoming DPR Worker Health and Safety Branch (WHS) exposure assessment document.

Pending products

Sulfuryl fluoride is proposed as a methyl bromide alternative. The U.S. EPA has approved a Section 3 registration of a new product, ProFume, with the same formulation as Vikane. Unlike Vikane, ProFume is approved for postharvest fumigation of a variety of food commodities. Since the California registration of ProFume is still pending, assessment of exposure from its use has not been included in this assessment. However, since Vikane is approved for use on non-food commodities, an assessment of worker and bystander exposure from such commodity use is included. It is not expected that worker and bystander exposure to sulfuryl fluoride during nonfood commodity fumigation would represent potential exposures under the pending ProFume use since the use of Vikane for nonfood commodity fumigation is infrequent (see Table 2 below). Therefore, if ProFume is approved in California in the future, worker and bystander exposures will need to be estimated.

Sulfuryl fluoride use

Potential exposure to sulfuryl fluoride comes from the approved label uses of its products. Table 2 summarizes major sulfuryl fluoride uses between 2000 and 2004 in California, as obtained using the California Pesticide Information Portal (CalPIP; DPR, 2006). Over 99% of the annual sulfuryl fluoride use is for structural pest control. Not shown in Table 2 are cases (0.0002-0.51% total) of nonlabel uses (nursery, ornamental turf, broccoli, cauliflower, olive) reported in the PUR database. Although the total pounds for each of these sites are included in the annual totals, these cases are possibly data entry errors for site or chemical. Potential exposure associated with nonlabel use is not addressed in this assessment.

Spatial (by county) and temporal (by month) distribution of sulfuryl fluoride use throughout California can be informative in evaluating potential exposure. The greatest use of sulfuryl fluoride occurs in Los Angeles County (Figure 2). The 2002 monthly sulfuryl fluoride use is depicted in Figure 3 and indicates that potential exposure may occur throughout the year.

It should be noted that most of the sulfuryl fluoride use occurs in southern California counties (Figure 2), hence, the monthly pattern represented in Figure 3 may not be reflective of all counties, especially those in the northern part of the state. Checking use in northern counties such as Sacramento, Mendocino, and Alameda shows use during all months of the year, however, as expected, the levels are much less than the state average.

Table 2. Major sulfuryl fluoride uses in California, 2000 – 2004. [a]

Site [b]	2000	2001	2002	2003	2004
			pounds -----(kg)-----		
Structural pest control	2,406,458 (1,082,906)	2,581,982 (1,161892)	3,044,000 (1,369,800)	3,106,409 (1,412,004)	3,265,283 (1,484,219)
Fumigation, commodity or other	1,445 (650)	24 (11)	0 (0)	2,202 (1,001)	1,114 (506)
Regulatory pest control	286 (129)	162 (73)	0 (0)	157 (71)	0 (0)
Vertebrate pest control	0 (0)	0 (0)	0 (0)	19 (9)	0 (0)
Annual total [c]	2,420,299 (1,100,281)	2,585,841 (1,163,628)	3,045,084 (1,370,288)	3,112,077 (1,414,580)	3,270,698 (1,486,680)

[a] Department of Pesticide Regulation (2006).

[b] Sites as recorded in the PUR database, defined as follows:

Structural pest control, includes any pest control work performed within or on buildings and other structures.

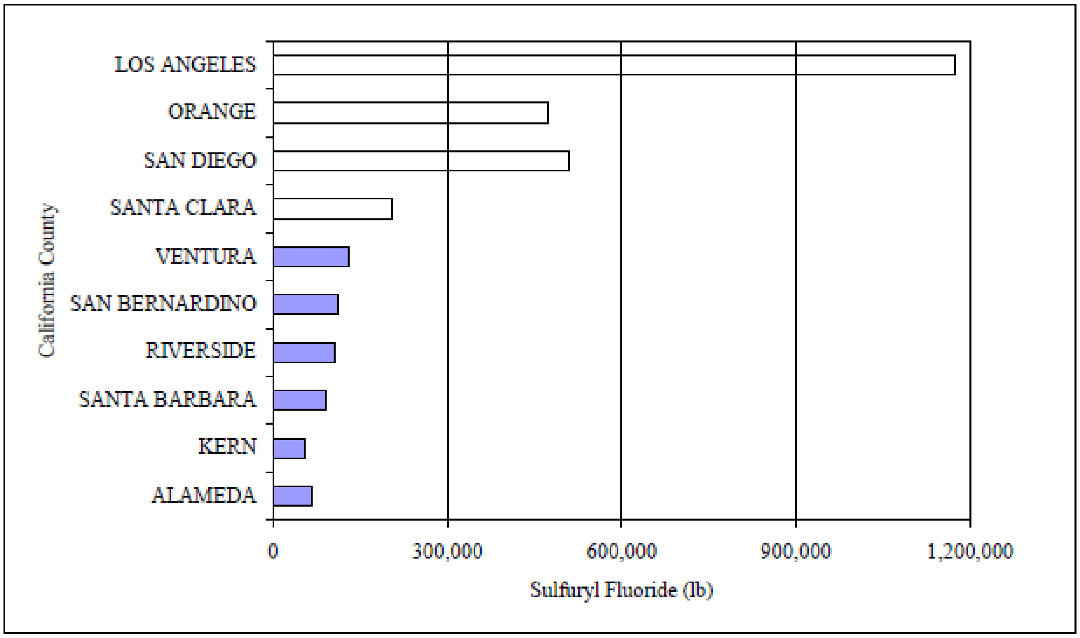
Fumigation, commodity refers to food and nonfood/nonfeed commodities such as pallets, dunnage, furniture, burlap bags, etc. (beds, mattresses). Fumigation, other refers to unspecified reported use of fumigant.

Regulatory pest control, includes any pest control work performed by public employees or contractors in the control of regulated pests.

Vertebrate pest control, includes any pest vertebrate pest control work performed by public agencies or work under the supervision of the State or county agricultural commissioner.

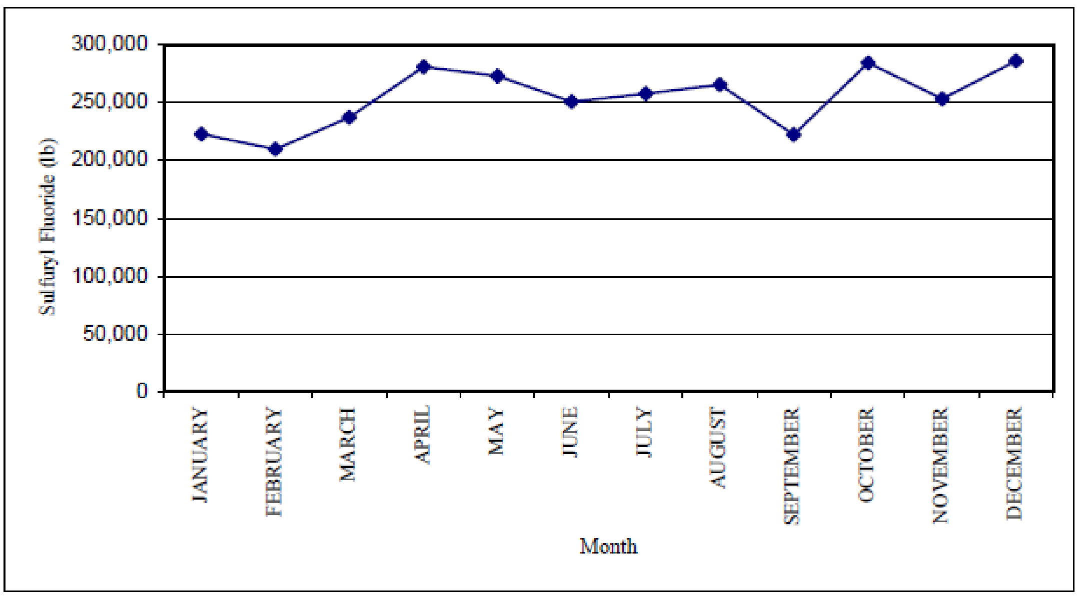
[c] Annual total is greater than the sum of each column since some sites are not reported in the table.

Figure 2. Sulfuryl fluoride use in 2004: Top 10 California counties. [a]



[a] Department of Pesticide Regulation (2006). Use data reported in pounds; multiply by 0.45 to convert to kilograms.

Figure 3. Monthly sulfuryl fluoride use in California in 2004. [a]



[a] Department of Pesticide Regulation (2006). Use data reported in pounds; multiply by 0.45 to convert to kilograms.

Reported illness and injury

A detailed account of the reported illnesses or injuries associated with sulfuryl fluoride exposure can be found in Appendix IV. The Pesticide Illness Surveillance Program (PISP) at DPR maintains a database of pesticide-related illnesses and injuries that occur in California. Between the years of 2000 and 2004, there were a total of 26 cases evaluated by PISP scientists and determined to be at least possibly related to sulfuryl fluoride exposure (Mehler, 2006). In structural fumigations with sulfuryl fluoride, chloropicrin is used as a warning agent and not as a pesticide. Therefore, the reported illness and injuries found to be solely related to chloropicrin will not be included in this report. Table 3 summarizes the types of activities and exposures associated with sulfuryl fluoride use.

Table 3. Summary of recorded exposures to sulfuryl fluoride obtained from the Pesticide Illness Surveillance Program database for the years of 2000 through 2004. [a]

Incident Setting/ Activity [c,d]	Type of Exposure [b,c]					
	Direct Spray/ Squirt	Spill/Other Direct	Drift	Residue	Unknown	Total Cases
Prison						
• Routine Indoor			3			3
• Routine Outdoor			2			2
Office/Business						
• Other					1	1
Service Establishment						
• Other				1		1
Single Family Home						
• Applicator	1					1
• Emergency Response				1		1
• Routine Indoor			3	5		8
• Routine Outdoor			1			1
• Other		2	1		2	5
Multi-Unit Housing						
• Routine Indoor				3		3
Total	1	2	10	10	3	26

[a] Department of Pesticide Regulation (Mehler, 2006).

[b] Types of Exposure

Direct Spray/Squirt: Material propelled by the application or mix/load equipment. Contact with the material can be by direct projection or ricochet. This includes exposure of mechanics working on application or mix/load equipment when the material is forced out by pressure.

Table 3 footnotes continued...

Spill/Other Direct: Includes contact made during an application or mixing/loading operation where the material is not propelled by the equipment or leaks, spills, etc., not related to an application.

Drift: Includes spray, mist, vapor or odor carried from the target site while an application or mix/load activity is taking place.

Residue: The part of a pesticide that remains in the environment for a period of time following the completion of an application. This includes an odor.

Unknown: Route of exposure is not known.

[c] Defined according to the Pesticide Illness Surveillance Program (PISP) Database User Documentation/Dictionary – Worker Health & Safety Branch, California Department of Pesticide Regulation, May 29, 2001.

[d] Activity

Applicator: Applies pesticides by any method or conducts activities considered ancillary to the application (e.g., cleans spray nozzles in the field).

Emergency Response: Emergency Response Personnel (Police, fire, hospital staff, ambulance and HAZMAT personnel) responding to a fire, spill, accident or any other pesticide incident in the line of duty.

Routine Outdoor: Conducts activities in an outdoor environment with minimal expectation for exposure to pesticides. This excludes field workers in agricultural fields. This includes gardeners who are not handling pesticides.

Routine Indoor: Conducts activities in an indoor environment with minimal expectation for exposure to pesticides. This includes people in offices and businesses, residential structures, etc. who are not handling pesticides.

Other: Activity is not adequately described by any other activity category. This includes but is not limited to: 1) being inside a vehicle; 2) dog groomers not handling pesticides; 3) individuals handling pesticide-treated wood; 4) two or more activities with potential for pesticide exposure.

There are no reports to PISP or in the scientific literature that associate a potential subchronic or chronic sulfuryl fluoride exposure with illness between 1995-1999. In 1986, Anger and coworkers reported a study in which California fumigation workers were evaluated for potential neurological effects of chronic exposure to sulfuryl fluoride, methyl bromide, or a combination of both fumigants. The mean duration of employment in fumigation work with sulfuryl fluoride, methyl bromide or the combination was 7, 8 or 11 years, respectively, and all groups had a minimum of 1 year experience. Workers in the methyl bromide and combination groups demonstrated some significantly different symptoms and signs in the neurobehavioral tests performed compared to controls. Sulfuryl fluoride workers, although tending to perform poorly in some tests, showed no statistical differences with the control (non-worker) group.

Between 1992-1993, the National Institute for Occupational Safety and Health (NIOSH) and the University of Miami conducted a cross-sectional study of 123 structural fumigation workers in south Florida to determine whether chronic exposure to sulfuryl fluoride or methyl bromide was associated with renal, pulmonary, or nervous system effects as compared to a non-worker control group (Calvert *et al.*, 1998). Workers had been employed in the fumigation industry for at least 6 months (median of 4 years) and were separated into sulfuryl fluoride workers (at least 80% jobs using sulfuryl fluoride) or methyl bromide workers (at least 50% jobs using methyl bromide). The median lifetime duration of sulfuryl fluoride or methyl bromide exposure was 2.85 or 1.2 years, respectively. Fumigation workers showed reduced performance in tests of median nerve function and manual dexterity and a greater prevalence of carpal tunnel syndrome compared to controls that was attributed to workplace ergonomics. On a pattern memory test (a measure of cognitive and visual memory), fumigation workers had a significantly poorer performance than controls. This poor performance was especially evident for sulfuryl fluoride workers, with an observed trend of poorer performance with increasing lifetime duration of sulfuryl fluoride exposure. Sulfuryl fluoride workers also showed a deficit in a smell identification test. Since chloropicrin is used as a warning agent in both methyl bromide and sulfuryl fluoride fumigations, any difference in performance between the two sets of workers is likely due to a difference in the effects of these two chemicals and not chloropicrin. This would be true for both this Florida study as well as the California study described above.

Label precautions and personal protective equipment

Sulfuryl fluoride gas is odorless and exposure to toxic levels may occur without warning or detection by the user. As stated on the product label, sulfuryl fluoride is a restricted use pesticide, poses a hazard to humans and domestic animals, is an extremely hazardous liquid and vapor under pressure, inhalation may be fatal, and the liquid phase may cause freeze burns (Dow AgroSciences LLC, 2000). According to Title 40 of the Code of Federal Regulations (40 CFR) Section 156.10(h)(2), the signal word Danger as well as the term Poison must appear on the label of products containing sulfuryl fluoride since it is an acute inhalation toxicity category I pesticide (Lewis, 1999).

In order to estimate potential sulfuryl fluoride exposure, precautions and personal protective equipment must be taken into consideration since any protection afforded by either may lower exposure accordingly. Since sulfuryl fluoride is a restricted use pesticide, its sale and use are limited to certified applicators and those under their direct supervision, thus controlling the number of persons with direct access to the fumigant.

The Vikane label requires the use of a NIOSH or Mine Safety and Health Administration approved positive pressure self-contained breathing apparatus (SCBA) or combination air-supplied/SCBA respirator whenever the air concentration of sulfuryl fluoride exceeds 5 ppm (Dow AgroSciences LLC, 2000). Given a proper seal of the face piece and use in the pressure demand or other positive pressure mode, the SCBA protection factor is 99.99% (Bollinger and Schutz, 1987). Respiratory protection is not specifically required during the introduction of the fumigant, which is performed by opening a valve on the product container located outside of the sealed structure and releasing the fumigant through leakproof tubing into the sealed structure. However, if a leak is detected, respiratory protection must be donned until the leak is sealed and sulfuryl fluoride air levels are determined to be 5 ppm or less. The label further requires that goggles or full face shield be worn during introduction of sulfuryl fluoride which reduces potential eye or face exposure to accidental leakage of the fumigant. No protective clothing is required, however, the label specifies that rubber gloves or boots are prohibited since such clothing may trap the gas or, in the case of an accidental leak or spill from the product container, the liquid. It should be noted that the proposed ProFume label would impose a stricter use of respiratory protection, requiring its use if sulfuryl fluoride levels exceed 1 ppm (Dow AgroSciences LLC, 2002).

California requirements

There are several California regulations directed to the use of sulfuryl fluoride or fumigants in general (3 CCR 6780, 6782; 8 CCR 3463, 5222, 5223; 16 CCR 1970-1974). All fumigation crews are required to be provided with and instructed in the use of a fumigation safety kit. Contents of the safety kit must be in proper condition and contain the following: a) manufacturer's instructions on use of the fumigant; b) 2 or more effective respiratory protection devices or other safety equipment; c) instructions for artificial respiration; and d) proper testing equipment (16 CCR 1971). According to 16 CCR 1973, the licensed fumigator is required to perform proper testing following aeration and, once aeration is complete, the fumigator releases the property for occupancy by posting a Notice of Reentry.

In regard to fumigation of enclosed spaces, California regulations require that at least 2 trained workers be present when the fumigant is introduced into the space, when the space is entered for purposes of facilitating aeration, and when the space is entered for the purpose of determining the fumigant concentration and personal protective equipment is required by the product label or regulation (3 CCR 6782 (a)). While one worker enters the enclosed space, the second worker should have immediate access to personal protective equipment in the event entry into the enclosed space is necessary for rescue (3 CCR 6782 (b)). The product label stipulates an additional requirement that at least 1 of the 2 workers be a certified applicator. However, the label also states that 2 persons need not be present if measurement of the sulfuryl fluoride air concentration within the space being fumigated is conducted remotely, i.e. air from within the enclosed space is drawn through a tube placed prior to sealing the space and connected to a measuring device on the outside of the fumigated space. The type of measuring device will depend upon the air concentration of sulfuryl fluoride. A Fumiscope Model D (Key Chemical and Equipment Company, Inc., Clearwater, FL) may be used for instantaneous measurement of sulfuryl fluoride air levels during the application phase (measuring range 0-1,000 oz/1,000 ft^3 or 0-1,000 g/m^3), but is not sufficiently sensitive to be used for testing of levels during the clearance phase. For instantaneous measurement of low air levels of sulfuryl fluoride (i.e., $\leq$5 ppm), MIRAN SapphIRe XL (Thermo Environmental Instruments, Franklin, MA) or GF1900 Sulfuryl Fluoride Monitor (Interscan Corporation, Chatsworth, CA) may be used.

Prior to the beginning of fumigation, it is required that warning signs be posted in plainly visible locations on or in the entrances to the space to be fumigated and are not to be removed until the fumigation and ventilation are complete and the space is safe for reentering (3 CCR 6782 (c), 8 CCR 5222-5223, 16 CCR 1974). Specifications and an approved warning sign, which comply with the provisions of sections 8505.9 and 8505.10 of the California Business and Professions Code, are provided in 16 CCR 1974. In addition to warning signs, 16 CCR 1970.3 requires that, prior to fumigation, structures need to be secured against entry by use of a secondary lock (device or barricade) on all outside doors to prevent entry by anyone other than the certified applicator.

Whenever an employee may be exposed to sulfuryl fluoride above the permissible exposure limit of 5 ppm or a more stringent limit imposed by the label, an employer must require workers to use respiratory equipment, employ continuous air monitoring (e.g., as mentioned above, using an instantaneous detection device with sufficient sensitivity such as GF1900 Sulfuryl Fluoride Monitor or MIRAN SapphIRe XL) to warn workers before the limit is reached, or perform work duties according to a DPR accepted Fumigation Safety Program which describes the methods, work practices, devices, or processes ensuring workers will not be exposed to levels exceeding the limit (3 CCR 6780 (b) and (c). A protocol to minimize worker exposure during aeration following a typical structural fumigation was developed by WHS and the Pest Control Operators of California (Gibbons, 1995) and was accepted under the provisions of this regulation. This protocol, known as the Tarpaulin Removal and Aeration Plan (TRAP), is not stated on the label but is provided in the Vikane Gas Fumigant Structural Fumigation Manual (Dow AgroSciences LLC, 1998).

Exposure scenarios

The exposure scenarios assessed in this document were derived from sulfuryl fluoride uses as a fumigant as well as its physical and chemical properties. Exposure depends upon the method of application (i.e., tarpaulin, taped or chamber fumigation), as well as fumigant use (i.e., structure or commodity).

Based on the use patterns presented earlier, sulfuryl fluoride is applied 12 months of the year. Fumigation workers have the potential for both acute and chronic exposure to the pesticide. There are three distinct phases involving workers during a structural fumigation (Andrews, 1995):

1. Closing or application phase: beginning with structural preparation and tarpaulin placement and ending when the fumigant release is completed;
2. Opening or commencement of aeration phase: the time ventilation is commenced is the period of time beginning when the seal is broken and ending when all seals/tarpaulin are removed (also defined in 16 CCR 1970.5); and
3. Certification phase: when the structure is certified safe for reentry by the licensee or field representative from the fumigation company (licensee).

Following certification, a fourth phase, denoted postclearance, signifies the time at which fumigation workers are no longer present and occupants of treated structures reenter those structures. (*Note*: Postclearance phase, as used herein, also refers to the time at which commodities may be handled.)

Fumigation workers

Structures, as well as other enclosures, to be fumigated are usually sealed by tarpaulin made of vinyl coated nylon, neoprene coated nylon, polyvinyl chloride coated nylon, or single use polyethylene of 4-6 mil (160-240 microns) thickness. Workers performing tarpaulin fumigations can be divided into two categories based on their activities: 1) tent crew workers, those who seal the structure to prevent fumigant leakage, and dismantle the tarpaulin at the commencement of aeration; and 2) fumigators or shooters, those who are licensed and introduce fumigant into the structure, initiate aeration and clear the structure for reentry (Calvert *et al.*, 1997; Contardi and Lambesis, 1996). In addition to their specialized duties, fumigators may also perform tent crew activities, however, tent crew workers cannot perform fumigator activities since they are not certified/licensed. During the introduction of pesticide, the fumigator may be exposed to either the liquid or gas phase of the fumigant. Both fumigators and tent crew workers may be exposed to the gas during the opening phase. The level of sulfuryl fluoride is expected to be very low at the time of certification, that is, if aeration procedures were followed correctly. Therefore, the fumigator is expected to have a minimal chance of exposure to the gas.

Similar to tarpaulin fumigation of structures, nonfood commodities (e.g., construction materials, household effects) may also be treated by tarpaulin fumigation. The activities and potential exposure scenarios of workers involved in tarpaulin fumigation of commodities are assumed to be comparable to those of structural fumigation workers above. However, another category of workers is involved in commodity fumigation, that is, commodity handlers who transfer commodities from the treatment site to a storage site or to the market during which time exposure to sulfuryl fluoride offgassing from the treated commodities may occur. Vikane use is only directed to nonfood commodities and does not allow the handling of these commodities prior to clearance of the fumigation site when sulfuryl fluoride air levels are confirmed to be 5 ppm or less. Commodities may also be treated by chamber fumigation in which case no tent crew workers are involved but fumigator and commodity handler may be exposed during their routine work activities.

Worker: bystanders

During a structural fumigation, worker bystanders, i.e., workers not directly involved in fumigator or tent crew activities, are not expected to have greater exposures than those workers performing those duties. Similarly, worker bystander exposure during commodity fumigation is not expected to exceed that of commodity handlers.

Non-worker: structure occupants

During the postclearance phase, occupants (residential, institutional and industrial) are permitted to return to treated structures and perform routine indoor activities. In this scenario, both adults and children have potential for exposure.

Non-worker: structural fumigation bystanders

During the application and aeration phases of a structural fumigation, non-worker bystanders, i.e., adjacent and nearby adults and children, have the potential for short-term exposure during their normal outdoor activities. Since there is no data regarding sulfuryl fluoride entering adjacent homes, indoor and outdoor air levels are assumed to be equal. Therefore, in addition to potential exposure during routine outdoor activities, bystanders may also be exposed while indoors. Potential exposure of bystander children and adults has been estimated separately for the application phase and aeration phase.

Non-worker: nonfood commodity fumigation bystanders

In contrast to the potential for short-term exposure at a structural fumigation site, exposure may occur on a continual basis at a commodity fumigation site, regardless of tarpaulin or chamber method. Therefore, commodity fumigation sites present a situation in which ambient air concentrations of sulfuryl fluoride may pose an ongoing potential for exposure to non-worker adult and child bystanders during their routine outdoor activities. Since no data is available on indoor air levels of homes located near commodity fumigations, it is assumed that non-worker bystanders may also be exposed while indoors. Unlike workers, bystanders may be present for longer durations than an 8-hour workday. Therefore, non-worker bystander exposures in association with a commodity fumigation site have been assessed.

Exposure scenarios

Tables 4a and 4b list the possible scenarios during which sulfuryl fluoride exposure may occur. Due to its physical properties, exposure to sulfuryl fluoride during normal use may occur through inhalation. Accidental dermal exposure to sulfuryl fluoride liquid may occur during the application phase while the licensed fumigator is releasing fumigant, but this type of exposure is not included in the present assessment.

Table 4. Sulfuryl fluoride exposure scenarios.

Site	Scenario
Activities during application, opening, and certification phases	
Structure/Enclosure (tarpaulin fumigation)	Fumigation workers: • Introducing fumigant • Monitoring during application (other than remote) • Ventilation (opening doors/windows, placing fans) • Opening seals • Removing tarpaulin • Folding tarpaulin • Monitoring for clearance • Removing equipment/cleaning Non-worker bystanders: • Adults, routine indoor/outdoor activities • Children, routine indoor/outdoor activities
Nonfood commodity (chamber or tarpaulin fumigation)	Fumigation workers: • Introducing fumigant • Monitoring during application (other than remote) • Ventilation (opening doors/windows, placing fans) • Opening seals • Removing tarpaulin (tarpaulin fumigation only) • Folding tarpaulin (tarpaulin fumigation only) • Monitoring for clearance • Removing equipment/cleaning Nonfumigation workers (bystanders): • Adults, routine work activities Non-worker bystanders: • Adults, routine indoor/outdoor activities • Children, routine indoor/outdoor activities
Activities during postclearance phase	
Site	Scenario
Structure/enclosure (residential, institutional, industrial)	Residents/occupants: • Adults, routine indoor activities • Children, routine indoor activities
Nonfood commodity fumigation	Postfumigation workers: • Commodity handlers Nonfumigation workers (bystanders): • Adults, routine work activities Non-worker bystanders: • Adults, routine indoor/outdoor activities • Children, routine indoor/outdoor activities

PHARMACOKINETICS

Potential routes of human exposure to sulfuryl fluoride gas are inhalation, dermal, and oral, with inhalation being the major route. The potential for dermal absorption or ingestion of this gas is minimal based on its physical and chemical properties (Torkelson et al., 1966; U.S. EPA, 1993). However, foods exposed to sulfuryl fluoride have been shown to retain fluoride residue which is minimized by following the label requirements of double bagging foods or completely eliminated by removing all unsealed foods prior to fumigation (Scheffrahn *et al.*, 1992b).

Termites fumigated with a nonlethal dose of radiolabeled sulfuryl fluoride excreted inorganic sulfate indicative of fluoride release *in vivo*. Other termite studies indicated metabolic changes characteristic of fluoride toxicity (Hayes and Laws, 1991). Cases of accidental overexposure to sulfuryl fluoride in humans have shown an elevation in plasma fluoride levels (Anonymous, 1987; Taxay, 1966). In animal toxicity studies, the long-term effects of sulfuryl fluoride are believed to be caused by excess fluoride whereas the short-term effects are those of the intact molecule (Hayes and Laws, 1991).

Bone retains about 60% of intravenous delivered fluoride, with a half-time uptake of about 13 minutes, whereas the plasma half-life of ingested fluoride is about 3 hours (World Health Organization (WHO), 1984). Fluoride is concentrated in the thyroid, aorta, and possibly kidney, but is primarily deposited in bone and teeth (Hardman *et al.*, 1996). Although 90% of fluoride filtered in the kidney is reabsorbed, it is the major route of fluoride excretion, with minor excretion through sweat and the intestine (Hardman *et al.*, 1996).

A pharmacokinetic study in rats exposed to sulfuryl fluoride was submitted by the registrant (Mendrala *et al.*, 2002). Rats were exposed to a nose-only dose of ^{35}S-sulfuryl fluoride at 30 and 300 ppm for 4 hours and urine and blood were collected over 7 days with tissues collected on the final day (Mendrala *et al*., 2002). Radioactivity was detected in the urine for the 7 days of study. The lungs contained the highest level of labeled-sulfur. In animals exposed to non-labeled sulfuryl fluoride, fluoride analysis revealed elevated levels in kidneys, brain, plasma and urine compared to untreated animals. Based on this study, an inhalation retention/absorption value of 18% was estimated (Section III.A. Pharmacokinetics, Lim, 2004). This value was used in the calculation of absorbed daily dosages in the present exposure assessment.

ENVIRONMENTAL CONCENTRATIONS AND RESIDUES

In late 2002, the California Air Resources Board (ARB) conducted monitoring of sulfuryl fluoride air concentrations around the perimeter of a home during all fumigation stages as requested by DPR as part of the Toxic Air Contaminant Program. However, the results presented for sulfuryl fluoride in the report were not valid due to extensive breakthrough of sulfuryl fluoride into the secondary collection tube (ARB, 2003). Additional method development is planned before further testing is conducted. Between 1999-2000, Dow AgroSciences conducted sulfuryl fluoride air monitoring around the perimeter of 2 California homes during all fumigation stages (Wright *et al*., 2003). Data presented in this report indicated that sulfuryl fluoride is detectable in ambient air surrounding structures during all fumigation stages, at distances 5 to 50 feet away. However, levels dissipate soon after clearance of the structure. The Wright *et al*. (2003) data will be discussed in more detail in the exposure calculation section below.

Based on sulfuryl fluoride's chemical properties (water insolubility, low reactivity) and its specialized use patterns, the U.S. EPA decided that significant environmental exposure was not expected to result from sulfuryl fluoride use. Therefore, wildlife toxicity data, an ecological risk assessment and supporting environmental fate data were not required for its reregistration (U.S. EPA, 1993), hence, there are no data directed to the environmental fate of sulfuryl fluoride.

EXPOSURE ASSESSMENT

Agricultural uses

There are no registered agricultural uses of sulfuryl fluoride to date. However, sulfuryl fluoride has been proposed as a methyl bromide alternative, so agricultural uses of sulfuryl fluoride similar to those of methyl bromide may be registered in the future and assessment of such uses will need to be considered.

Off-site/ambient exposure

The general public, especially residents of areas in the vicinity of commodity fumigation facilities (i.e., bystanders), may be exposed to airborne residues of sulfuryl fluoride. As mentioned in the section on environmental concentrations and residues, ambient sulfuryl fluoride air concentrations surrounding structural fumigations have been reported by Wright *et al*. (2003) and considered in estimating non-worker bystander exposures. There are no current data directed to ambient air surrounding nonfood commodity fumigation facilities; therefore, exposure estimates for bystanders to such facilities are based on assumed sulfuryl fluoride air levels as discussed in the exposure calculation section below.

Residential, institutional and industrial uses

The sulfuryl fluoride exposure estimates determined in this assessment include those for workers and non-workers based on residential, institutional and industrial scenarios presented in Tables 4a and 4b. Chemical-specific personal air monitoring or on-site air sampling data were used in calculating exposures. The estimates for workers and non-workers are grouped into short-term, intermediate-term, annual and lifetime exposures as defined by WHS policy (Andrews, 2001). Short-term exposure is defined as that exposure which may occur daily but not exceeding 7 days; short-term exposures occurring 1 day or less have been specified herein as acute. Intermediate-term exposure is that exposure lasting more than 7 days but substantially less than 1 year. Annual and lifetime exposures are defined as the average daily exposure amortized over 365 days and the annual average daily exposure amortized over one's lifetime (75 year default for both genders), respectively.

Determination of sulfuryl fluoride air concentration

In the field, structural fumigation workers use a Fumiscope (Key Chemical and Equipment Company, Inc., Clearwater, Florida) to measure sulfuryl fluoride air concentrations above 50 ppm. For lower concentrations expected at the end of fumigation, especially at the end of aeration, more sensitive instrumentation, such as MIRAN SapphIRe XL (Thermo Environmental Instruments, Franklin, MA) or GF1900 Sulfuryl Fluoride Monitor (Interscan Corporation, Chatsworth, CA), is used to measure sulfuryl fluoride in the range of 0-50 ppm (valid range 0.5-50 ppm). All of these instruments provide instantaneous measures.

Sulfuryl fluoride air monitoring may be accomplished by pumping air across a charcoal tube which adsorbs the sulfuryl fluoride present in the air being sampled. NIOSH protocol number 6012 (NIOSH, 1994) provides a sulfuryl fluoride air monitoring procedure based on the original method of Bouyoucos and Melcher (1979) comprising the collection of sulfuryl fluoride onto charcoal solid sorbent tubes, desorption with sodium hydroxide, and analysis by ion chromatography. Huff and Murphy (1995) report a revised sulfuryl fluoride air monitoring method based upon 2 previous Dow Chemical Company methods, the aforementioned 1979 Bouyoucos and Melcher method as well as a method developed by Murphy and Contardi (1994). The 1995 Huff and Murphy method was validated to detect 10-1000 µg sulfuryl fluoride (i.e., 0.1-10 ppm, assuming 24 L air volume), with a limit of detection of 2.1 µg (i.e., 0.021 ppm, assuming 24 L volume). Briefly, laboratory spikes were prepared by syringe injection of a known amount of sulfuryl fluoride made directly onto a 1 g charcoal tube which was separated into an 800 mg front section and a 200 mg back section to detect sample breakthrough. The spikes were prepared at a relative humidity of 80% and attached to a vacuum pump with a flow rate of 100 ml/minute for 0.25-4 hours. The front and back tube sections were handled separately and desorbed with 0.04 N sodium hydroxide with shaking for 1 hour. A portion of the extract from each sample was boiled to dryness, reconstituted with water and fluoride concentration was measured by ion selective electrode analysis and quantitated using a fluoride standard curve. The average recovery of sulfuryl fluoride using the 1995 Huff and Murphy method was 66% considering all spikes, and 65% considering only spikes prepared at 80% humidity and 100 ml/minute flow rate. Based on their method validation, Huff and Murphy suggested using a 66.1% analytical recovery to correct all samples (1995).

The 1994 Murphy and Contardi method average recovery was 92% considering laboratory spikes prepared at 80% humidity and 100 ml/minute flow rate, and 91% considering all samples (i.e., prepared at 80% and 92% humidities and 50 and 100 ml/minute flow rates). However, this 1994 method differed from the 1995 Huff and Murphy method in only 2 ways: 1) sulfuryl fluoride laboratory spikes were prepared using an inhalation chamber or a gas sample bag with known sulfuryl fluoride air concentration except for the 20 µg spike which was prepared by direct injection; and 2) fluoride concentration was quantitated by a standard addition technique rather than by a fluoride standard curve. Huff and Murphy (1995) offer no explanation as to the difference in recoveries between the 2 methods. Although the authors do not show data for reference solutions prepared by directly injecting sulfuryl fluoride into 20 ml of 0.04 N sodium hydroxide solution at the same volume used to prepare the laboratory (charcoal) spikes, they state that reference solutions yielded a recovery comparable to that of the laboratory spikes and hence known volumes of sulfuryl fluoride can be accurately delivered via syringe for preparing spikes (Huff and Murphy, 1995). Also, since the recoveries for reference solutions and laboratory spikes were comparable, yet less than 100%, Huff and Murphy concluded that sulfuryl fluoride was incompletely hydrolyzed by the sodium hydroxide solution (1995).

For the purposes of this exposure assessment, recoveries from field spike data supplied in Shurdut, 1995, Contardi and Lambesis, 1996, and Wright *et al*., 2003 were calculated based on intended (i.e., nominal) levels of sulfuryl fluoride rather than that level detected in the reference solutions.

Exposure calculations

Sulfuryl fluoride exposure estimates calculated for acute, short-term, intermediate-term, annual and lifetime exposures for applicable exposure scenarios are presented in Tables 7, and 13-15. For short-term exposures (i.e., those with durations of 7 days or less) the WHS estimates the highest ("upperbound") exposure an individual may realistically experience as a result of a label-prescribed activity. Short-term exposures occurring for 24 hours or less were considered acute exposures in the present assessment, and upperbound exposure values were also used in their estimates. In order to estimate an upperbound daily exposure, WHS generally uses the estimated population 95th percentile of daily exposure. A population estimate is used instead of a sample statistic because sample maxima and upper-end percentiles, in samples of the sizes usually available to exposure assessors, are both statistically unstable and known to underestimate the population values. The population estimate, on the other hand, is more stable because it is based on all the observations rather than a single value; moreover, it is adjusted, in effect, for sample size, correcting some of the underestimation bias due to small samples. A high percentile is estimated, rather than the maximum itself, because in theory, the maximum value of a lognormal population is infinitely large. In practice, exposures must be bounded because a finite amount of active ingredient is applied. The use of a high percentile acknowledges that the assumed lognormal distribution is probably not a perfect description of the population of exposures, especially at the upper extremes. The population 95th percentile is estimated, rather than a higher percentile, because the higher the percentile the less reliably it can be estimated.

To estimate intermediate- and long-term exposure of workers, the average daily exposure is of interest because over these periods of time, a worker is expected to encounter a range of daily exposures (i.e., the WHS assumes that with increased exposure duration, repeated daily exposure at the upperbound level is unlikely). Unlike workers, residents returning to fumigated structures are not expected to encounter a range of daily exposures throughout the year, but rather an exposure based on a single annual treatment. Therefore, both short-term and annual residential exposure estimates (Table 12) were based on upperbound values, i.e., 95th percent upper prediction limits for the dissipation curve of sulfuryl fluoride air concentration (Figure 5). Lifetime exposure of residents was based on unbiased predicted means (Figure 4) since repeated annual exposure of residents at the upperbound is unlikely.

The arithmetic mean is used rather than the geometric mean or the median because, although it can be argued that the latter statistics better indicate the location of the center of a skewed distribution, it is not the center that is of interest in exposure assessment, but the *expected magnitude* of the long-term exposure. While extremely high daily exposures are low-probability events, they do occur, and the arithmetic mean appropriately gives them weight in proportion to their probability. In contrast, the geometric mean gives decreasing weight as the value of the exposure increases, and the median gives no weight whatsoever to extreme exposures.

Daily exposure estimate

The exposure estimates provided in this assessment are expressed as absorbed daily dosages (ADD) in milligrams of sulfuryl fluoride per kilogram of body weight per day (mg/kg/day). The formulae used to calculate the estimated exposure to sulfuryl fluoride are listed below.

Equation 1. Calculation of sulfuryl fluoride air concentration (ppm).

$$\text{sulfuryl fluoride (ppm)} = \frac{\mu g \times 24.45}{VS \times 102.07} = \frac{\mu g \times 0.2392}{VS}$$

where,

VS is the sample volume in liters (one mole of sulfuryl fluoride occupies 24.45 liters at 25 °C, and molecular weight of 102.07 g/mole).

Equation 2. Conversion of sulfuryl fluoride from ppm to mg/m^3.

$$\text{ppm} = 0.2392 \times \text{mg/m}^3$$

Equation 3. Conversion of sulfuryl fluoride from mg/m^3 to ppm.

$$\text{mg/m}^3 = 4.17 \times \text{ppm}$$

Equation 4. Calculation of absorbed dose inhaled (AD_i, mg/hour).

$$AD_i = C_{sf} \times IR \times (1\text{-}PF) \times AF$$

where,

C_{sf} is air concentration of sulfuryl fluoride (mg/m^3);
IR is inhalation rate (m^3/hr) during activity;
PF is the protection factor afforded by personal protective equipment, when applicable (e.g., PF for SCBA is 0.9999); and
AF is the absorption factor (18%; Lim, 2004).

Equation 5. Calculation of absorbed daily dosage (ADD, mg/kg/day).

$$ADD = \frac{AD_i \times DD}{\text{body weight (kg)}}$$

where,

AD_i is the absorbed dose inhaled as calculated in Equation 4; and
DD is the daily duration of the exposure, i.e., time spent performing an activity in which exposure may occur, expressed in hours/day.

Worker exposure

For fumigation workers, estimates of exposure rely on factors including the duration and frequency of a worker's exposure, the activity being performed, and sulfuryl fluoride air levels at the end of the application phase. One inhalation exposure monitoring study that addresses these factors has been reported (Contardi and Lambesis, 1996) and is briefly described below. Regarding the duration and frequency of exposure, fumigation workers have the potential for exposure to sulfuryl fluoride daily and throughout the year. A summary of the duration and frequency of sulfuryl fluoride exposure derived from California fumigation crew activities monitored by Contardi and Lambesis (1996) is provided in Table 5. A study conducted by NIOSH surveyed 123 structural fumigation workers in Florida who reported a range of 0.5 to 32 years of employment in the industry, with a median of 4 years (Calvert *et al.*, 1998). For lifetime exposure as presented in Tables 7a-b, WHS currently uses the default values of 75 years for the average life expectancy (both genders) and 40 years for performing the same job.

To estimate potential sulfuryl fluoride exposure of tent crew workers and fumigators during typical tarpaulin fumigation of homes, Contardi and Lambesis (1996) conducted monitoring in Broward County, Florida in October 1993, and in Orange and Los Angeles Counties, California in November 1993 and May 1994, respectively. Their study was completed in October 1994 and amended in August 1996 to reflect adjusted sample recovery based on a reevaluation of the analytical methodology (Huff and Murphy, 1995).

Since fumigant aeration procedures differed between California and Florida, only the monitoring studies conducted in Phase 2: Santa Ana (Orange County) and Phase 3: El Monte (Los Angeles County) were used to estimate exposure in this assessment. Specifically, California workers performed the opening phase of a fumigation using TRAP, in which an exhaust fan is used to initiate ventilation before tarpaulin removal; Florida workers did not use this method. TRAP was originally developed in 1990 by WHS in cooperation with the Pest Control Operators of California with revisions in 1994 and 1995 (Gibbons, 1995). The average sulfuryl fluoride application rate (equilibrium concentration) used in the California homes was 11 oz/1,000 ft^3 (range 7-16 oz/1,000 ft^3 or 7-16 g/m^3), with an average high air temperature of 70° F (range 60-85° F) and average exposure time of 25 hours (range 22-28 hours). Although application rates vary with fumigant loss rate (i.e., HLT), temperature, target pest, and exposure time, it is WHS practice is to assess exposure based upon the highest possible exposure, i.e., at the highest application rate. Consistent with the current product label (Dow AgroSciences, LLC 1998 and 2000), as well as recommended by the Environmental Monitoring Branch of DPR (Fan and Walters, 2002), the maximum sulfuryl fluoride application rate ranges between 60-160 oz/1,000 ft^3 (60-160 g/m^3; ~20 hours exposure time). Since the Contardi and Lambesis study (1996) was performed at less than the maximum application rate, worker personal breathing zone sulfuryl fluoride air levels reported in the study (Table 6) may underestimate exposures ~5-15x. Therefore, estimates based upon the study's average application rate of 11 oz/1,000 ft^3 (11 g/m^3) provided in Table 7a were extrapolated to estimate exposure at the maximal application rate of 160 oz/1,000 ft^3 or 160 g/m^3 (i.e., values were multiplied by 160÷11=14.5; Table 7b).

In the Contardi and Lambesis study (1996), field spike samples were prepared at two fortification levels (i.e., nominal or intended levels) by injecting a given volume of sulfuryl fluoride onto charcoal tubes which were connected to an air sampling pump with a flow rate of 50 or 100 ml/minute for a duration of 4 or 8 hours, respectively. Field spikes were prepared in the field on all 5 worker monitoring days in Santa Ana and on 3 of the 5 monitoring days in El Monte. Travel spikes were prepared in a similar manner to field spikes, however, air was drawn through the charcoal tubes for only 10-15 minutes. To quantify the actual amount of sulfuryl fluoride delivered, reference solutions were prepared by directly injecting sulfuryl fluoride into a sodium hydroxide solution at the same volume used for field and travel spike preparation. The amount of fluoride ion released by hydrolysis of the sulfuryl fluoride in the reference solution or charcoal samples was quantitated by fluoride selective electrode analysis and standard addition technique. This analytical method was similar to the 1995 Huff and Murphy method except that Huff and Murphy used a fluoride standard curve rather than a standard addition technique to quantitate the sample fluoride level.

Based on the 1995 Huff and Murphy report, Contardi and Lambesis submitted to DPR an amended worker exposure study which was reported to address a negative bias in the analytical method due to incomplete alkaline hydrolysis of sample sulfuryl fluoride (1996). Upon review of the amended report, the following key points were used in the present exposure assessment to calculate sulfuryl fluoride concentrations in worker activity-specific personal air monitoring samples:

- The amended report used geometric rather than arithmetic means to calculate average field spike recoveries and worker monitoring samples. According to WHS practice, the present assessment has used arithmetic means in calculating data averages.
- In the amended report, charcoal tube front sections were analyzed for all samples. For Santa Ana samples, back sections were analyzed only if >5 µg sulfuryl fluoride was detected in the sample front section. For El Monte samples, back sections were analyzed only if >25 µg sulfuryl fluoride was detected in the front section (including field spike samples). Therefore, sulfuryl fluoride levels may be underestimated in samples without back section analysis.
- The arithmetic mean of reference solution recovery was 86% for Santa Ana and 84% for El Monte sites.
- The arithmetic mean of field spike recovery was 95% for the Santa Ana site, 102% for the El Monte site, or an average of 98% for both sites (Appendix I, Table A-1).
- The amended report used an analytical recovery of 91%, as well as the 95% field spike recovery to correct the Santa Ana field samples. The El Monte samples were corrected for the 91% analytical recovery only since field spike recovery at this site was >100%.
- Since the field spike recoveries were greater than 90% for both the Santa Ana and El Monte sites, the present exposure assessment did not correct worker activity-specific personal air monitoring sample according to current assessment practices. Field sample sulfuryl fluoride concentrations from the Contardi and Lambesis (1996) report Tables 20-29 (without field spike correction) were used in estimating sulfuryl fluoride air concentrations in worker breathing zones summarized in Table 6 of the present assessment.

Air in the breathing zones of fumigators and tent crew workers was sampled during task-specific activities: fumigant application, opening and certification phases of structural fumigations using personal air sampling devices consisting of a 1 g charcoal tube connected to an air sampling pump set at a flow rate of 50 or 100 ml/minute. For task-specific activity exposure, pumps drew air samples only during the time period in which the activity was being performed. Although full shift sampling was performed, these data were not used in this assessment since pumps continued to draw air during nonexposure times, i.e., tarping, travel time, lunch and other breaks, estimated to account for 70% of the monitoring period and is presumed to dilute actual exposure. In addition, Contardi and Lambesis (1996) noted that, after quantitation, some fumigator full shift samples contained less sulfuryl fluoride than the task specific samples collected simultaneously. The exposure estimates for fumigators and tent crew workers are presented in Tables 7a-b and were derived from personal air sampling conducted during task-specific activities as follows:

- Fumigant introduction, period during which a fumigator released gas into a structure.
- Opening structure to initiate aeration, period during which a fumigator placed ventilation fans and opened doors and windows of a structure.

- Removal of ground snakes, period during which workers removed snakes, i.e., water or sand filled bags used to weigh down the tarpaulin to form a seal at the base of the structure.
- Opening of ground seams, period during which workers unclamped tarpaulin at ground level.
- Opening of roof seams, period during which workers unclamped tarpaulin on the roof.
- Structure closing after the first 1 hour of aeration, period during which a fumigator closed windows and locked doors of a structure at the end of the minimum active aeration period. The crew leaves the site sealed during the remainder of the 6- or 8-hour minimum aeration period. In typical practice, the fumigator returns the next day to test the structure for clearance.
- Tarpaulin folding, period during which workers rolled and folded tarpaulin removed from the treated structure after the initiation of aeration.
- General detarping, period from arrival at a site following the treatment period (average 25 hr) to the end of detarping. General detarping scenario represents the total potential daily exposure a tent crew worker may experience from activities including removing ground snakes, opening roof and ground seams, tarp folding and general clean-up.
- Testing for clearance, period during which a fumigator entered a treated structure to test for clearance at the end of the minimum aeration period. In this study, all California fumigators tested for clearance the day following the initiation of aeration.

Based on the Contardi and Lambesis report (1996) or WHS defaults, Tables 5 and 6 summarize values used in Equations 4 and 5 to calculate exposures presented in Tables 7a-b. The 95th percentile values in Table 6 were used to calculate short-term absorbed daily dosage, and the arithmetic mean values in Table 6 were used to calculate annual and lifetime absorbed daily dosage in Tables 7a-b. Sulfuryl fluoride air concentrations were not adjusted for respiratory protection in Table 6, however, a protection factor of 99.99% (Bollinger and Schutz, 1987) was used to adjust the short-term, annual and lifetime absorbed daily dosage values shown in Tables 7a-b for fumigator activities during which SCBA were reported to be worn during the study (Contardi and Lambesis, 1996).

Currently, there are no air monitoring data directed at nonfood commodity handlers. Therefore, estimates for this group found in Table 7a are based on an assumed exposure to a maximal sulfuryl fluoride air concentration of 5 ppm since levels greater than this would require use of SCBA according to the Vikane label.

Table 5. Inhalation rate and exposure duration values used in calculating worker exposure to sulfuryl fluoride.

Scenario	Average daily duration [a,b]	Average frequency [a,c]	Average annual duration [a,d]	Inhalation rate [e]
Fumigator:	hours/day	days/week	days/year	m^3/hour
Introducing fumigant	0.17	4	196	1.0
Opening structure to initiate aeration	0.35	3.67	180	1.0
Closing following first hour of aeration	0.31	3.67	180	1.0
Testing for clearance	0.16	4	196	1.0
Tent crew or fumigator [f]:				
Ground seam opening	0.67	3.67	180	1.6
Roof seam opening	1.27	3.67	180	1.6
Ground snake [g] removal	0.34	3.67	180	1.6
Tarpaulin folding	1.14	3.67	180	1.6
General detarping [h]	2.73	3.67	180	1.6

[a] Data from one work week (5 days) of daily observation and timing of 3 crews of structural fumigation workers during their routine activities in Santa Ana and El Monte, California (November 1993 and May 1994) submitted by the registrant (Contardi and Lambesis, 1996).

[b] The average time spent performing a given activity per day; value used in Equation 5 to calculate short-term and annual absorbed daily dosages in Tables 7a-b.

[c] The average number of days a given activity is performed per week; value used to calculate the average annual duration.

[d] The average number of days a given activity is performed per year (average frequency (days/week) x 49 weeks/year); value used to calculate annual average daily dosage in Tables 7a-b. Weeks worked per year was based on national averages of paid holidays and vacations collected by U.S. Department of Labor (2004).

[e] Default inhalation rates (Andrews and Patterson, 2000) according to an assumed activity level for a given activity. Value used in Equation 4.

[f] Fumigators may perform tent crew activities in addition to their certified/licensed activities.

[g] "Snake" refers to water or sand filled tubes or bags used to weigh down the tarpaulin around the base of the structure.

[h] General detarping involved continuous monitoring during snake removal, opening seams (roof or ground), tarp folding and general clean-up.

Table 6: Mean sulfuryl fluoride air concentrations and upperbound values used to estimate exposures of California structural fumigation workers. [a]

Scenario	n [b]	Mean (sd) [c]	95th percentile [d]
		ppm [c]	
Fumigator:			
Introducing fumigant	16	6.17 (16.66)	15.9
Opening structure to initiate aeration [e]	22	92.45 (70.14)	271
Closing structure following first hour of aeration [e]	17	4.75 (8.14)	18.36
Testing for clearance	3	0.72 [f] (0.21)	n/a [g]
Tent crew or fumigator [h]:			
Ground seam opening	9	4.39 (4.63)	26.59
Roof seam opening	21	3.29 (4.20)	14.09
Ground snake [i] removal	15	2.28 (4.67)	7.03
Tarpaulin folding	8	0.80 (0.87)	2.83
General detarping	16	6.22 (15.42)	24.17

[a] Chemical-specific data from personal air monitoring of structural fumigation workers in Los Angeles (phase 2) and Orange (phase 3) Counties submitted by registrant (Contardi and Lambesis, 1996). No adjustment for sample recovery was made since field spike recoveries averaged greater than 90% for both phases (see Appendix I).

[b] n, number of samples for a given activity performed by California fumigation workers.

[c] Mean (arithmetic) and standard deviation (sd) of sulfuryl fluoride concentration in parts per million (ppm), as collected onto charcoal sorbent tubes for the duration of the specified activity (Huff and Murphy, 1995). Values used to estimate intermediate-term, annual and lifetime exposures in Tables 7a-b.

[d] 95th percentile, used to estimate short-term exposures in Tables 7a-b. Derived from the arithmetic mean and standard deviation of the natural log (ln) transformed data, AM_{lt} and SD_{lt}, respectively, where n=number of samples:

95^{th} percentile = antiln$\{AM_{lt} + (t_{(0.95;\, n-1)} \times SD_{lt})\}$.

[e] Sulfuryl fluoride air concentration reported for this scenario does not account for the use of respiratory protection required by the label.

[f] This mean air concentration is likely less than that following the label-specified 6-hr minimum aeration since samples were collected when fumigators returned to homes 12-24 hours following the initiation of aeration. Therefore, this value was not used in estimating long-term fumigator exposure during clearance (Tables 7a-b).

[g] n/a, not applicable. A 95th percentile was not estimated due to the small sample size (n=3).

[h] Fumigators may perform tent crew activities in addition to their certified/licensed activities.

[i] "Snake" refers to water or sand filled tubes or bags used to weigh down the tarpaulin around the base of the structure.

Table 7a: Sulfuryl fluoride exposure estimates of California structural fumigation workers: Submaximal application rate. [a,b]

Scenario	Respiratory protection [b]	Short-term ADD [c]	Intermediate-term average ADD [d]	Annual average ADD [e]	Lifetime average ADD [f]
		mg/kg/day			
Fumigator:					
Introducing fumigant	no	0.03	0.01	0.006	0.003
Opening structure to initiate aeration	yes	0.0001	0.00004	0.00002	0.000009
Closing following first hour of aeration	yes	0.000006	0.000002	0.0000008	0.0000004
Testing for clearance	no [g]	0.009 [h]	0.009 [h]	0.005 [h]	0.003 [h]
Fumigator activities, total	yes [i]	0.04 [j]	0.02 [j]	0.01 [j]	0.006 [j]
Fumigator plus tent crew activities [k]	yes [i]	1.17 [l]	0.31 [l]	0.15 [l]	0.08 [l]
Tent crew [k]:					
Ground seam opening	no	0.30	0.05	0.02	0.01
Roof seam opening	no	0.31	0.07	0.04	0.02
Ground snake [m] removal	no	0.04	0.01	0.007	0.003
Tarpaulin folding	no	0.06	0.02	0.008	0.004
General detarping [n]	no	1.13	0.29	0.14	0.08
Commodity handler [o]	no	0.43 [p]	NA [q]	0.001 [p]	0.001 [p]

[a] Chemical-specific data from personal air monitoring of structural fumigation workers in Los Angeles and Orange Counties submitted by registrant (Contardi and Lambesis, 1996), except for "Fumigator: Testing for clearance" and "Commodity handler" values (see footnote *h* and *p*, respectively). Values in this table were rounded to 2 places beyond the decimal point, except in those cases where the number is less than one hundredth. In all those cases, there is just a single number at the end of the zeros. Values used to estimate exposure are presented in Tables 5 and 6.

[b] Protection factor of 99.99% (Bollinger and Schutz, 1987) was used to adjust sulfuryl fluoride air concentrations in Table 6 for fumigators who were reported to wear positive pressure self-contained breathing apparatuses during opening to initiate aeration and during closing following initial hour of aeration. For these cases, this protection factor was used in Equation 4 to calculate absorbed dose inhaled.

[c] Short-term ADD (absorbed daily dosage) refers to the estimated daily exposure from performing a given activity for no more than a 7-day period, and was calculated using the 95th percentile sulfuryl fluoride air concentration (Table 6) and Equations 4 and 5, where body weight is 70 kg and inhalation rate and average daily duration is listed in Table 5. Value applies to both male or female adults. For example,

Equation 4: Absorbed dose inhaled (AD_i):

$$AD_i = C_{sf} \times IR \times (1\text{-}PF) \times AF$$

where,
- C_{sf} sulfuryl fluoride air concentration (Table 6 (ppm) x 4.17 mg/m^3)
- IR is inhalation rate (m^3/hr) during activity (Table 5)
- PF is a protection factor, i.e., 0.9999 with and 0 without SCBA
- AF is the absorption factor (18%; Lim, 2004)

Table 7a footnotes continued…

Equation 5: Absorbed daily dosage (ADD):

$$ADD = AD_i \times \text{daily duration (hr/day)} / \text{body weight (kg)}$$

where, body weight is 70 kg (default for both genders)
daily duration is found in Table 5

[d] Intermediate-term average ADD refers to an absorbed daily dosage greater than one week (short-term) but less than one year (annual), and calculated using Equations 4 and 5 (as in footnote *c*) and using the mean sulfuryl fluoride air concentration for the given activity (Table 6), body weight of 70 kg, and inhalation rate and average daily duration listed in Table 5. Value applies to both male or female adults.

[e] Annual average ADD refers to an absorbed daily dosage resulting from performing a given activity during one year, and was calculated by amortizing the intermediate-term average ADD (footnote *d*) over one year. The intermediate-term average ADD was multiplied by the average annual duration (Table 5) and divided by 365 days, assuming sulfuryl fluoride is used during every month of the year. Value applies to both male and female adults.

[f] Lifetime average ADD refers to an absorbed daily dosage resulting from performing a given activity for 40 years during one's lifetime of 75 years (Worker Health and Safety default values representing both genders); calculated as Annual average ADD multiplied by 40/75. Value applies to both male and female adults.

[g] As reported by Contardi and Lambesis (1996), workers did not wear SCBA during this activity per label directions. The label states that, since Interscan and MIRAN gas analyzers give immediate readings, respiratory protection is not required when clearing with these instruments after having completed the initial 1 hour aeration. If a reading indicates air levels >5ppm, instructions state to leave the area immediately. SCBA would then be required.

[h] Since only 3 California samples were reported by Contardi and Lambesis (1996), the table values were calculated from the maximum sulfuryl fluoride concentration allowed for clearance, i.e., 5 ppm, levels above this would require SCBA. Frequency of activity was assumed to be equal to the frequency of fumigant introduction (Table 5).

[i] A protection factor was only applied to exposure from activities during which respiratory protection was reported to be worn (see footnote *b*).

[j] Sum of the individual fumigator-specific activity ADDs within the same column, i.e., "Introducing fumigant" + "Opening structure to initiate aeration" + "Closing following first hour of aeration" + "Testing for clearance".

[k] Fumigators may perform tent crew activities in addition to their certified/licensed activities.

[l] Sum of the individual fumigator-specific activity ADDs (footnotes *j* and *k*) plus "General detarping" ADD within the same column.

[m] "Snake" refers to water or sand filled tubes or bags used to weigh down the tarpaulin around the base of the structure.

[n] General detarping involved continuous monitoring during snake removal, opening seams (roof or ground), tarp folding and general clean-up. This value also represents worker bystander exposure during the first hour of aeration.

[o] Commodity handler refers to workers who may handle postfumigation nonfood commodities following clearance at the maximum allowed sulfuryl fluoride air concentration according to the Vikane label, i.e., 5 ppm.

[p] Values are estimated from an assumed exposure to 5 ppm sulfuryl fluoride (maximum level allowed by the Vikane label). Duration and frequency was assumed to be 8 hours/day (acute). Since Vikane use on nonfood commodities is infrequent (See Table 2), longer term exposures were estimated at a frequency of 1 day /year (annual), and 40 years over a 75-year lifetime.

[q] NA, not applicable, i.e., intermediate-term exposure is not presently anticipated for this scenario. If nonfood commodity use of sulfuryl fluoride increases in the future, this exposure will need to be reassessed.

Table 7b: Sulfuryl fluoride exposure estimates of California structural fumigation workers: Extrapolation to maximal application rate. [a]

Scenario	Respiratory protection [b]	Short-term ADD [c]	Intermediate-term average ADD [d]	Annual average ADD [e]	Lifetime average ADD [f]
		------ mg/kg/day ------			
Fumigator:					
Introducing fumigant	no	0.42	0.16	0.09	0.05
Opening structure to initiate aeration	yes	0.002	0.0005	0.0002	0.0001
Closing following first hour of aeration	yes	0.00009	0.00002	0.00001	0.000006
Testing for clearance	No [g]	0.009 [h]	0.009 [h]	0.005 [h]	0.003 [h]
Fumigator activities, total	yes [i]	0.43 [j]	0.17 [j]	0.09 [j]	0.05 [j]
Fumigator plus tent crew activities [k]	yes [i]	16.85 [l]	4.39 [l]	2.17 [l]	1.16 [l]
Tent crew [k]					
Ground seam opening	no	4.42	0.73	0.36	0.19
Roof seam opening	no	4.45	1.04	0.51	0.27
Ground snake [m] removal	no	0.59	0.19	0.09	0.05
Tarpaulin folding	no	0.80	0.23	0.11	0.06
General detarping [n]	no	16.42	4.22	2.08	1.11

[a] Chemical-specific data from personal air monitoring of structural fumigation workers in Los Angeles and Orange Counties submitted by registrant (Contardi and Lambesis, 1996), except for "Fumigator: Testing for clearance" and "Commodity handler" values (see footnote *h* and *p*, respectively). Since the study average application rate (11 oz/1000 ft^3 or 11 g/m^3) was less than the maximal allowed application rate, sulfuryl fluoride air concentrations in Table 6 were multiplied by a factor of 14.5 (i.e., 160÷11) and used in Equation 4 to reflect potential exposure at a maximal application rate of 160 oz/1000 ft^3 (160 g/m^3; Fan and Walters, 2002). Values in this table were rounded to 2 places beyond the decimal point, except in those cases where the number is less than one hundredth. In all those cases, there is just a single number at the end of the zeros.

[b] Protection factor of 99.99% (Bollinger and Schutz, 1987) was used to adjust sulfuryl fluoride air concentrations in Table 6 (x14.5) for fumigators who were reported to wear positive pressure self-contained breathing apparatuses during opening to initiate aeration and during closing following initial hour of aeration. For these cases, this protection factor was used in Equation 4 to calculate absorbed dose inhaled.

[c] Short-term ADD (absorbed daily dosage) refers to the estimated daily exposure from performing a given activity for no more than a 7-day period, and was calculated using the 95th percentile sulfuryl fluoride air concentration (Table 6, multiplied by 14.5) and Equations 4 and 5, where body weight is 70 kg and inhalation rate and average daily duration is listed in Table 5. Value applies to both male or female adults. For example,

Equation 4: Absorbed dose inhaled (AD_i):

$$AD_i = C_{sf} \times IR \times (1\text{-}PF) \times AF$$

where,
- C_{sf} sulfuryl fluoride air concentration (Table 6 (ppm) x 14.5 x 4.17 mg/m^3)
- IR is inhalation rate (m^3/hr) during activity (Table 5)
- PF is a protection factor, i.e., 0.9999 with and 0 without SCBA
- AF is the absorption factor (18%; Lim, 2004)

Table 7b footnotes continued…

Equation 5: Absorbed daily dosage (ADD):

$$ADD = AD_i \text{ x daily duration (hr/day) / body weight (kg)}$$

where, body weight is 70 kg (default for both genders)
daily duration is found in Table 5

[d] Intermediate-term average ADD refers to an absorbed daily dosage greater than one week (short-term) but less than one year (annual), and calculated using Equations 4 and 5 (as in footnote *c*) and using the mean sulfuryl fluoride air concentration for the given activity (Table 6) multiplied by 14.5, body weight of 70 kg, and inhalation rate and average daily duration listed in Table 5. Value applies to both male or female adults.

[e] Annual average ADD refers to an absorbed daily dosage resulting from performing a given activity during one year, and was calculated by amortizing the intermediate-term average ADD (footnote *d*) over one year. The intermediate-term average ADD was multiplied by the average annual duration (Table 5) and divided by 365 days, assuming sulfuryl fluoride is used during every month of the year. Value applies to both male and female adults.

[f] Lifetime average ADD refers to an absorbed daily dosage resulting from performing a given activity for 40 years during one's lifetime of 75 years (Worker Health and Safety default values representing both genders); calculated as Annual average ADD multiplied by 40/75. Value applies to both male and female adults.

[g] As reported by Contardi and Lambesis (1996), workers did not wear SCBA during this activity per label directions. The label states that, since Interscan and MIRAN gas analyzers give immediate readings, respiratory protection is not required when clearing with these instruments after having completed the initial 1 hour aeration. If a reading indicates air levels >5ppm, instructions state to leave the area immediately. SCBA would then be required.

[h] Values were calculated from the maximum sulfuryl fluoride concentration allowed for clearance, i.e., 5 ppm. Levels above this would require SCBA, so the 14.5 multiplication factor was not applied. Frequency of activity was assumed to be equal to the frequency of fumigant introduction (Table 5).

[i] A protection factor was only applied to exposure from activities during which respiratory protection was reported to be worn (see footnote *b*).

[j] Sum of the individual fumigator-specific activity ADDs within the same column, i.e., "Introducing fumigant" + "Opening structure to initiate aeration" + "Closing following first hour of aeration" + "Testing for clearance".

[k] Fumigators may perform tent crew activities in addition to their certified/licensed activities.

[l] Sum of the individual fumigator-specific activity ADDs (footnotes *j* and *k*) plus "General detarping" ADD within the same column.

[m] "Snake" refers to water or sand filled tubes or bags used to weigh down the tarpaulin around the base of the structure.

[n] General detarping scenario represents the sum of a tent crew worker's daily activities. This value also represents worker bystander exposure during the first hour of aeration.

In 1989, the WHS reported worker exposure to both sulfuryl fluoride and methyl bromide during aeration following fumigation of homes (Gibbons *et al.*, 1989). Although this data partially served as the basis for the development of TRAP used in California to reduce worker exposure to fumigants (Gibbons, 1995), it is excluded from use in this assessment since it does not reflect current California sulfuryl fluoride handling practices. Data collected from worker monitoring studies conducted in Florida (Contardi and Lambesis, 1996; O'Neill and Sanderson, 1991) are also excluded from this assessment since fumigation workers in Florida do not follow the aeration procedures outlined by TRAP.

Non-worker exposure

Individuals may be exposed to sulfuryl fluoride inside homes or other structures following clearance of the fumigated structure. Californians older than 11 years of age are estimated to spend 87% of their time indoors, 62% (14.9 hr) inside their own home and 25% (6 hr) inside other structures (Jenkins *et al.*, 1992). The duration of time spent indoors by children aged 11 years and younger was estimated by Wiley *et al.* (1991) and averaged 20.5 hr (range 19.5 to 21.6 hr). Table 8 provides a summary of the average daily exposure duration, along with the default inhalation rates and body weights, used in Equations 4 and 5 to estimate the residential and bystander exposures in Tables 13-17 unless otherwise specified.

Table 8. Inhalation rate, body weight and exposure duration values used in calculating residential exposure to sulfuryl fluoride.

Age [a]	Daily inhalation rate [b]	Indoor exposure duration [c]	Outdoor exposure duration [c]	Median body weight [b]
Years	m^3/hr	Hr/day	hr/day	kg
< 1	0.19	17	1	8
1-2	0.28	17	1	13
3-5	0.35	16	2	18
6-8	0.42	15	2	26
9-11	0.56	14	2	36
12-14	0.56	15	1	50
15-18	0.60	15	1	61
Adults	0.83	15	1	70

[a] Both genders are represented within each age group.

[b] Default values based on data from Layton, 1993 (Andrews and Patterson, 2000), averaged for both genders within an age group. These inhalation rate values were used in Equation 4 to calculate exposures in Tables 13-17.

[c] From Jenkins *et al*., 1992 and Wiley *et al*., 1991, averaged values for both genders and age groups based on time spent at home indoors. Since adults and children spend most of their time at home, these times represent the longest daily duration spent indoors and were used in Equation 5 to calculate exposures in Table 13.

Resident/occupant exposure (postclearance)

Data for postfumigation sulfuryl fluoride air concentrations inside homes were derived from a monitoring study as reported by Shurdut (1995). This study collected post-clearance air samples from 7 California homes (5 single-story, 2 double-story) and 8 Florida homes in March and April 1994, respectively. As indicated in the worker exposure study presented above, aeration procedures differ between the 2 states, so only California data were used to estimate exposure in this assessment. Briefly, 7 California homes were treated with sulfuryl fluoride at an average rate of 13.6 oz/1,000 ft^3 (13.6 g/m^3; equilibrium concentration). Eight-hour continuous air samples from 3 rooms of each home were collected onto charcoal tubes connected to an air pump set at a flow rate of 50 ml/minute for 8-hour intervals, starting at 0, 8, 16, 24, 32, and 40 hours postclearance. The amount of sulfuryl fluoride collected on the tubes was determined following alkaline hydrolysis, fluoride selective electrode detection, and standard curve quantitation. The analyzed amount of sulfuryl fluoride was then corrected for a 65% recovery (Appendix II, Table A-2) as determined from average field spike recoveries (Appendix II, Table A-3). The limit of quantitation in the Shurdut study (1995) was 0.0875 µg/L, or 0.02 ppm. The sample values from the 3 rooms for each house were averaged for each time interval (Table 9).

The homes treated with sulfuryl fluoride in the Shurdut study (1995) experienced less than the maximal application rates. Nonetheless, the rate of clearance of sulfuryl fluoride following aeration was not adjusted for maximal application rates, as was done with occupational exposures. All residential structures are aerated to 5 ppm or less, and residential bystander indoor exposures are dependent only upon the rate of dissipation of sulfuryl fluoride from 5 ppm to non-detectable levels. The data from the Shurdut study (1995) indicate that indoor air concentrations do not go to zero in 24 hours. Thus, there is the likelihood of short-term (seven days or less) as well as acute exposure to indoor air concentrations of sulfuryl fluoride. Measurable air concentrations were still present in the seven homes at 48 hours after aeration. Unfortunately, no measurements were conducted beyond that point, so it was necessary to estimate the short-term air concentrations using alternate methods.

Table 9. Sulfuryl fluoride dissipation from homes following tarpaulin fumigation: Summary of three-room average air concentrations 0-48 hours postclearance. [a]

Time postclearance	Mean sulfuryl fluoride concentration [b]					
	0-8 hr	8-16 hr	16-24 hr	24-32 hr	32-40 hr	40-48 hr
	ppm [c]					
House No.						
1	0.27	0.08	0.06	0.05	0.04 [d]	0.04
2	1.82	1.35	0.58	0.90	1.07	0.48
3	0.72	0.29	0.05	0.05	0.08	0.06
4	0.18	0.29	0.26	0.05	0.11	0.05
5	1.08	0.66	0.20	0.13	0.18	0.09
6	0.08	0.02	0.01	0.02	0.01	0.02
7	0.28	0.20	0.11	0.09	0.08	0.06

[a] Chemical-specific air monitoring data (California only) collected during the first 48 hours following minimum clearance requirements for Vikane fumigation of a structure (Shurdut, 1995). Based on California field spikes, a 65% field spike recovery factor has been applied (Appendix II, Table A-3).

[b] Arithmetic mean of 8-hour continuous air sampling in 3 rooms per house (Appendix II, Table A-2).

[c] ppm, parts per million.

[d] Since a pump malfunction was noted for this house at this time interval (Shurdut, 1995), this value is the average of air samples from 2 rooms rather than 3.

Generally, it is assumed that air concentrations of chemicals decline over time in a log-linear fashion (USEPA, 1997). Using the average 8-hour sulfuryl fluoride air concentrations for each house at each time interval (Table 9), regression analyses of the natural log (*ln*) concentration on hours postclearance, expressed as the midpoint of the 8-hour interval, was performed to select the best-fitting model (SAS PROC REG, V8.0). A full explanation of the models is in Appendix VI. The slopes and intercepts have been rounded to the nearest hundredth in this presentation.

The equation for Model 1 is:

$$\ln(\text{conc(ppm)}) = -1.04 - 0.04 \text{ (hours postclearance)}$$

Where: -1.04 is the intercept (ln conc.)
and –0.04 is the slope

$R^2 = 0.20$
Adjusted $R^2 = 0.18$

This model only accounts for the variation associated with the time since clearance. All 42 observations shown in Table 9 are used in the regression without accounting for any potential difference between houses. The regression Model 1 is statistically significant because of the large number of degrees of freedom associated with the error term (40 df), the p-value for the F-test is 0.003. However the percent of variation explained by Model

1, the R^2 = 0.20 (Table 10), is quite low, and indicates that, realistically, the model does not accurately predict air concentrations following aeration.

Examination of the data indicates that there are marked differences in the starting sulfuryl fluoride concentrations of the homes. Shurdut (1995) states: "These initial differences may be attributed to the amount of fumigant introduced into the structure and remaining prior to aeration, 'tightness of the house' or ability of the house to retain fumigant following introduction and during aeration period, low level desorption of the gas from permeable media, and internal voids." The model can be modified to take into account differences between houses. The regression is then performed using 'dummy variables' to quantify the effect of houses as a main effect. In this case, house 7 was the base case, meaning that when all 6 dummy variables are zero, house 7 ln(conc) is estimated.

Model 2. The equation for Model 2 is:

> ln(conc(ppm)) = -1.13 – 0.04 (hours postclearance) – 0.57 (h1) + 2.08 (h2) + 0.007 (h3) + 0.07 (h4) + 0.81 (h5) – 1.75 (h6)
>
> R^2 = 0.89
> Adjusted R^2 = 0.87

The large increase in the R^2 from 0.20 to 0.89 (and the adjusted R^2 from 0.18to 0.87) indicates that there are significant differences between the mean concentrations of the 7 houses (Table 10). The large increase in R^2 indicates that there are potentially seven different regressions lines with different elevations on the Y-axis determined by the respective $(\bar{X},\bar{Y})$ values for each house. Thus, the house main effect accounts for the difference in $\bar{Y}$ values (air concentrations) between houses. As long as the interaction between hours and house is not statistically significant the 7 regression lines would be parallel.

To evaluate whether the slopes for the decline in concentration over time for the 7 houses are the same, the interaction terms into the regression model are added in.

Model 3. The equation for Model 3 is:

> ln(conc(ppm)) = -1.13 – 0.04 (hours postclearance) – 0.57 (h1) + 2.08(h2) + 0.007(h3) + 0.07(h4) + 0.81(h5) – 1.75 (h6) - 0.007 (hrh1) + 0.01 (hrh2) – 0.02 (hrh3) – 0.0008 (hrh4) – 0.02 (hrh5) + 0.01 (hrh6)
>
> R^2 = 0.91
> Adjusted R^2 = 0.86

Compared to Model 2, the addition of the interaction terms adds little to the R^2 and decreases the adjusted R^2, indicating that the interaction terms are not statistically significant (Table 10). Therefore, the slopes of the 7 house lines are the same, resulting in parallel lines, separated by the difference in the intercepts and the mean concentrations.

Table 10. Model analysis [a] of sulfuryl fluoride dissipation data collected from 7 fumigated homes [b].

Log-linear models Terms in model	Adjusted R^2
1) Hr	0.18
2) Hr + House main effects	0.87
3) Hr + House main effects + House x Hr interactions	0.86

[a] Regression analyses of the natural log (*ln*) concentration on hours postclearance, expressed as the midpoint of the 8-hour interval, were performed using SAS V8.0.

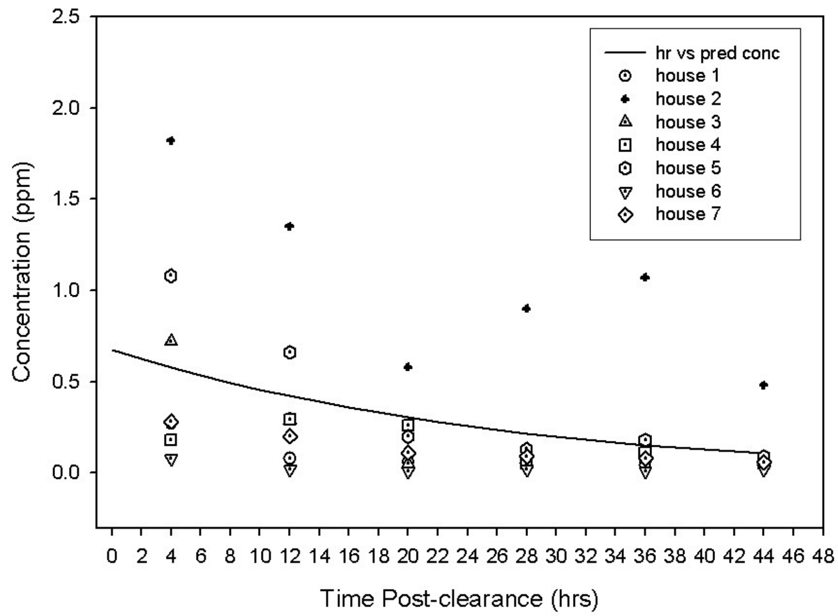
[b] Chemical-specific air monitoring data collected during the first 48 hours following minimum clearance requirements for Vikane fumigation of a structure (Shurdut, 1995); 64.6% recovery factor applied.

The regression analyses summarized in Table 10 indicated that there were differences between the houses in average concentration. This is shown by the large increase in R^2 from Model 1 to 2. However, the houses had a common dissipation rate, indicated by the very small change in R^2 from Model 2 to 3.

Model 2, including the terms for overall house differences, was identified as best because it is the simplest model that accounts for most of the variance that can be accounted for by any of these models. For the purpose of predicting sulfuryl fluoride levels in future fumigated houses, however, Model 1 was used. For houses not yet observed, it is unknown what average concentration might apply. Therefore, differences between houses must be treated as noise in the model when predicting concentrations in future houses.

A regression equation fit to the logarithms of concentration predicts mean log concentration at a given time. Simple back-transformation of the predicted log concentration by taking the antilog is biased, underestimating the true mean concentration. Therefore, instead of the simple antilog, the unbiased back-transformation method of Bradu and Mundlak (1970), implemented in SAS (Powell, 1991), was used. Unbiased mean sulfuryl fluoride air concentrations were predicted for the midpoint of each time interval using Model 1. Concentrations between these points were interpolated by fitting a smooth function (Figure 4) to the unbiased predicted means (TableCurve 2D V2.03, Equation 7103, log y = (a + cx + ex2)/(1 + bx + dx2); R2 = 1) over the two-day collection period. Unbiased predicted mean concentrations were used to calculate lifetime exposure estimates (Table 13).

Figure 4. Sulfuryl fluoride dissipation from the air inside homes following clearance [a]: Unbiased predicted mean sulfuryl fluoride air concentrations during the first 48 hours following aeration[b].

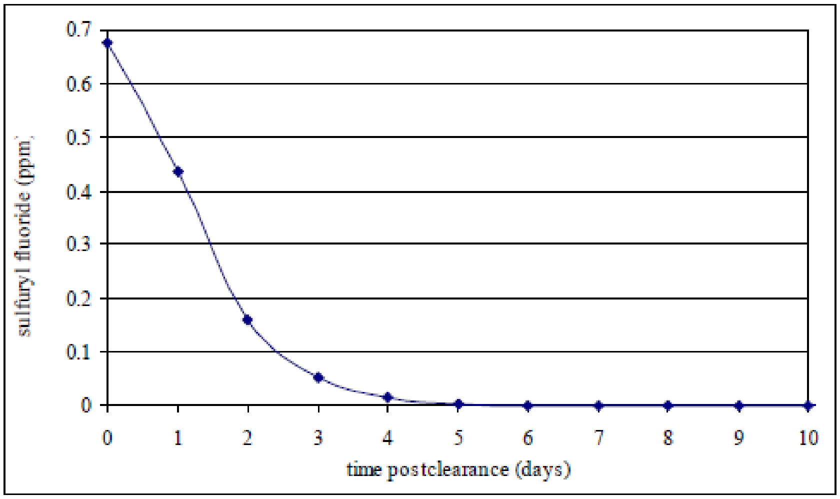


[a] Based on chemical-specific air monitoring data (California only) collected during the first 48 hours following minimum clearance requirements for Vikane fumigation of a structure (Shurdut, 1995).

[b] Using model 1 of Table 10 (i.e., regression analyses of the natural log (*ln*) concentration on hours postclearance), unbiased predicted mean sulfuryl fluoride air concentrations were estimated over time.

As depicted in Figure 5, the predicted concentration rapidly decreases during the first two days following clearance, and tends toward zero around day 6 or 7. The mean sulfuryl fluoride air concentration of 0.095 ppm for the interval from 0-7 days was calculated with TableCurve2D as the area under the mean dissipation curve divided by the length of the interval (Table 11). This 7-day mean was used to estimate lifetime residential exposure with an assumed 7-day exposure duration and once-a-year exposure frequency (Table 13).

Figure 5. Sulfuryl fluoride dissipation from the air inside homes following clearance [a]: Unbiased predicted mean sulfuryl fluoride air concentrations [b].

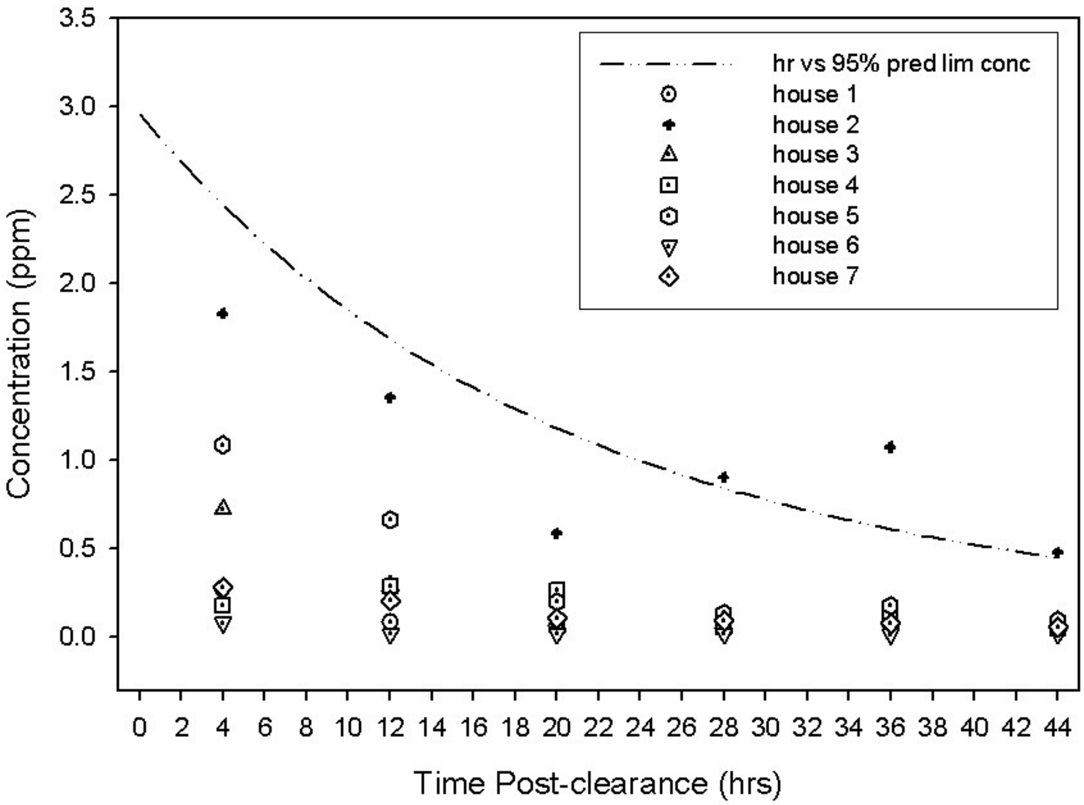


[a] Based on chemical-specific air monitoring data (California only) collected during the first 48 hours following minimum clearance requirements for Vikane fumigation of a structure (Shurdut, 1995).

[b] Using Model 1 of Table 10 (i.e., regression analyses of the natural log (*ln*) concentration on hours postclearance), unbiased predicted mean sulfuryl fluoride air concentrations were estimated over time.

To estimate acute, short-term, and annual exposures (Table 13), 95% prediction limits for sulfuryl fluoride air concentration were calculated for the midpoint of each time interval using Model 1. [The 95% prediction limit is the concentration that, with 95% probability, will not be exceeded by the next observed concentration (Neter *et al*., 1985).] Concentrations between these points were interpolated by fitting a smooth function (Figure 6) to the 95% prediction limits (TableCurve 2D V2.03, Equation 7103, log y = (a + cx + ex2)/(1 + bx + dx2); R2 = 1). TableCurve2D was used to calculate areas under the dissipation curve in Figure 7 for intervals up to 30 days after clearance, and the mean for each interval was calculated as the area divided by the number of hours in the interval (Table 12). The first day of residential reentry, i.e., the time following clearance by a certified fumigator according to the label requirements, is expected to be the period of highest sulfuryl fluoride air concentrations as illustrated in Figure 7. Therefore, acute exposure was estimated for resident scenarios and presented in Table 13. These acute exposures were based on the mean 95% prediction limit concentrations for the interval from 0-1 day postclearance (1.78 ppm; Table 12).

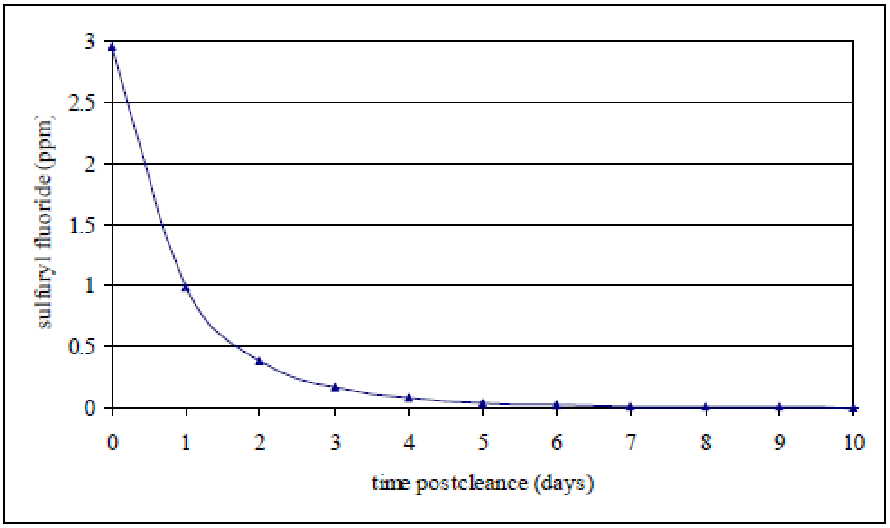
Figure 6. Sulfuryl fluoride dissipation from the air inside fumigated homes following clearance[a]: 95% prediction limit sulfuryl fluoride air concentrations during the first 48 hours[b].



a/ Based on chemical-specific air monitoring data (California only) collected during the first 48 hours following minimum clearance requirements for Vikane fumigation of a structure (Shurdut, 1995).

b/ Using Model 1 of Table 10 (i.e., regression analyses of the natural log (*ln*) concentration on hours postclearance), 95% prediction limits for sulfuryl fluoride air concentrations were calculated for the observed values of hours.

Figure 7. Sulfuryl fluoride dissipation from the air inside fumigated homes following clearance[a]: 95% prediction limit sulfuryl fluoride air concentrations[b].



a/ Based on chemical-specific air monitoring data (California only) collected during the first 48 hours following minimum clearance requirements for Vikane fumigation of a structure (Shurdut, 1995).
b/ Using Model 1 of Table 10 (i.e., regression analyses of the natural log (*ln*) concentration on hours postclearance), 95% prediction limits for sulfuryl fluoride air concentrations were calculated for the observed values of hours.

Also illustrated in Figure 7, the air concentration of sulfuryl fluoride decreases over time, and tends toward zero around day 7 postclearance. The half-life appears to be approximately 16 hours. Therefore, residential short-term and annual exposures in Table 13 were estimated using the mean 95% prediction limit concentrations for the intervals from 0-7 days postclearance (0.42 ppm; Table 12). Although Worker Health and Safety routinely estimates annual exposure based on mean values (as in Table 7), annual residential exposure in Table 13 of this exposure assessment was based on upperbound sulfuryl fluoride air concentration (95% prediction limits) since annual exposure of residents results from a once-a-year exposure period. This approach was used to protect those individuals entering homes at the upperbound of sulfuryl fluoride air concentrations in a one-year period. Since an individual is not likely to enter a home at the upperbound every year, lifetime residential exposures were estimated using predicted mean sulfuryl fluoride air concentrations.

Table 11. Unbiased predicted mean sulfuryl fluoride air concentration in fumigated homes following clearance. [a]

Postclearance interval [b]	Predicted mean $[SF]_a$ [c]
days	ppm [d]
0-1	0.436
0-2	0.298
0-3	0.216
0-4	0.166
0-5	0.133
0-6	0.111
0-7 [e]	0.095

[a] Using a log-linear model in terms of hours, unbiased predicted mean concentrations were calculated for the observed values from Shurdut, 1995 (Appendix II, Table A-2).

[b] The postclearance interval is period of time (days) following clearance. Clearance is designated as time 0, i.e., the time at which a structure would be considered cleared according to the minimum Vikane label requirements (i.e., 6 hours of aeration and testing air concentration until 5 ppm is attained). Time is represented on the x-axis of Figure 4.

[c] Predicted mean $[SF]_a$, sulfuryl fluoride air concentration, refers to the average amount of sulfuryl fluoride in the air based on unbiased predicted means using Model 1 (Table 10). Calculated as the area under the curve in Figure 4 divided by the indicated time interval.

[d] ppm, parts per million.

[e] The predicted mean sulfuryl fluoride concentration after 7 days postclearance was considered to be zero in estimating lifetime residential exposure (see Table 13).

Table 12. Upperbound (95% prediction limit) sulfuryl fluoride air concentrations in fumigated homes following clearance. [a]

Postclearance interval [b]	$[SF]_a$ mean prediction limit [c]
days	ppm [d]
0-1 [e]	1.781
0-2	1.208
0-3	0.893
0-4	0.700
0-5	0.573
0-6	0.484
0-7 [f]	0.418

[a] Using a log-linear model in terms of hours, 95% prediction limits were calculated for the observed values from Shurdut, 1995 (Appendix II, Table A-2).

[b] The postclearance interval is period of time (days) following clearance. Clearance is designated as time 0, i.e., the time at which a structure would be considered cleared according to the minimum Vikane label requirements (i.e., 6 hours of aeration and testing air concentration until 5 ppm is attained). Time is represented on the x-axis of Figure 5.

[c] $[SF]_a$, sulfuryl fluoride air concentration, mean prediction limit refers to the average amount of sulfuryl fluoride in the air based on upper 95% prediction limits using Model 1 (Table 10). Calculated as the area under the curve in Figure 5 using TableCurve2D (V2.03), divided by the indicated time interval.

[d] ppm, parts per million.

[e] The 24-hour mean prediction limit was used to calculate residential acute sulfuryl fluoride exposure for reentry immediately following minimal clearance requirements for fumigated structures (Table 13).

[f] The 7-day mean prediction limit was used to calculate residential short-term and annual sulfuryl fluoride exposure upon reentry into fumigated structures following clearance (Table 13).

Table 13. Sulfuryl fluoride exposure estimates for residents following clearance of fumigated homes. [a]

Resident age	Acute (24-hr) ADD [b]	Short-term ADD [c]	Annual ADD [d]	Lifetime average ADD [e]
years old	mg/kg/day			
< 1	0.57	0.13	0.0025	-
1-2	0.49	0.12	0.0023	-
3-5	0.42	0.10	0.0019	-
6-8	0.32	0.08	0.0015	-
9-11	0.29	0.07	0.0014	-
12-14	0.23	0.05	0.0010	-
15-18	0.20	0.05	0.0009	-
adult	0.24	0.06	0.0011	0.0002

[a] Chemical-specific air monitoring data collected during the first 48 hours following minimum clearance requirements for Vikane fumigation of a structure, 65% recovery factor applied (Shurdut, 1995). Estimates are for both genders within the age group specified.

[b] Acute ADD, absorbed daily dosage, was calculated as an upperbound sulfuryl fluoride exposure during the first 24 hours of reoccupation using equations 4 and 5, a mean prediction limit sulfuryl fluoride air concentration of 1.78 ppm (see Table 12), and values in Table 8, example given for adults:

Equation 4: Absorbed dose inhaled (AD_i), acute:

$$AD_i = C_{sf} \times IR \times (1-PF) \times AF$$

where,
- C_{sf} sulfuryl fluoride air concentration (1.78 ppm x 4.17 mg/m^3)
- IR is inhalation rate (m^3/hr) during activity (0.83; Table 8)
- PF protection factor, none apply, i.e., PF = 0
- AF is the absorption factor (18%; Lim, 2004)

Equation 5: Absorbed daily dosage (ADD), acute:

$$ADD = AD_i \times \text{daily duration (hr/day)} / \text{body weight (kg)}$$

where,
- AD_i, acute (calculated in Equation 4)
- body weight is 70 kg (Table 8)
- daily duration is 15 (Table 8)

[c] Short-term ADD, absorbed daily dosage, refers to the upperbound sulfuryl fluoride daily exposure that may occur during the course of sulfuryl fluoride dissipation following clearance of a structure when residents are permitted reentry. The duration of exposure was assumed to be 7 days based on the dissipation curve of Figure 5. Short-term exposure was calculated using Equations 4 and 5 (as above in footnote *b*) with the mean prediction limit sulfuryl fluoride air concentration (0.42 ppm in Table 12) for time interval 1-7 days, and default age and gender appropriate inhalation rates, body weights and durations (Table 8).

[d] Annual ADD, absorbed daily dosage, was calculated as an upperbound exposure using the short-term absorbed daily dosage (see footnote *c* above) multiplied by total days of exposure (7 days, predicted from Figure 5) divided by 365 days/year. As noted in the text, annual exposure of residents was estimated as an upperbound since annual exposure results from a once-a-year treatment which may be at the upper-end of exposure.

[e] Lifetime average ADD, absorbed daily dosage, was estimated using Equations 4 and 5 (described in footnote *b*) for adults using the unbiased predicted mean sulfuryl fluoride air concentration of 0.095 ppm (Table 11) for the interval of 0-7 days following clearance (sulfuryl fluoride air concentration was assumed to be zero after 7 days based on Figure 4). The result of Equation 5 was amortized over a lifetime of adult exposure (from age 19-75 yr, or 57 yrs), i.e., 7days/yr for 57 of 75 years (75 yrs = default lifetime for both genders).

There are no studies specifically directed to potential exposure of individuals reentering institutional or industrial structures following clearance. However, sulfuryl fluoride dissipation from an institutional or industrial structure should be comparable to that described by Shurdut (1995) for residential structures. Since it is estimated that Californians older than 11 years of age spend 25% of the day indoors away from their homes (Jenkins *et al.*, 1992), it is assumed that an individual's exposure resulting from reentering an institutional or industrial structure following clearance will be less than that exposure experienced by residents listed in Table 13.

Bystander exposure

Non-worker bystander exposure associated with structural fumigations may occur at the same frequency as that for residents reentering cleared structures. However, unlike fumigation workers who are only present for short periods of time to perform specific activities, and unlike residents of fumigated structures who are not permitted entrance until clearance, bystanders are not restricted from being in the proximity of the site during any phase of a fumigation. Therefore, bystanders are at risk for exposure to sulfuryl fluoride at any time during the fumigation, from application through clearance, with the greatest potential for exposure likely during aeration. It is expected that any bystander exposure during the postclearance phase would not exceed that of occupants returning to their homes (Table 13).

As mentioned previously, a report by Wright *et al*. (2003) provides data for sulfuryl fluoride air concentrations surrounding a structure (i.e., home) during all stages of a fumigation. These data have been reviewed for consideration in estimating sulfuryl fluoride exposure to bystanders during their routine outdoor activities while a structural fumigation is in progress (DiPaolo and Frank, 2003; Wofford, 2003). Consisting of two study phases, air monitoring was conducted within and surrounding two homes during the application, aeration, and postclearance phases of a fumigation performed at 16 oz/1,000 ft^3 (16 g/m^3) which is ~4-10x less than the maximal of 60-160 oz/1,000 ft^3 (60-160 g/m^3). Meteorological conditions were recorded during the air monitoring at both study sites. Phase one of the study involved two replicate fumigations (24-hour exposure period) performed at one unfurnished home in Rancho Cordova, CA (Sacramento County) in May 1999 according to current California application and aeration procedure (i.e., TRAP; Gibbons, 1995). Data from this Rancho Cordova home was not used to estimate upperbound and average bystander exposure in the present assessment since only 2 replicates were performed, and surrogate air concentrations from those measured during worker general detarping activities (Table 6) were used to estimate bystander exposure during TRAP. However, the data from phase one aeration by TRAP indicated that after the first 2 hours of aeration, sulfuryl fluoride was no longer detectable in ambient air samples collected (DiPaolo and Frank, 2003). Therefore, the duration of bystander exposure during TRAP was assumed to be 2 hours for the exposures estimated in Tables 15a-b.

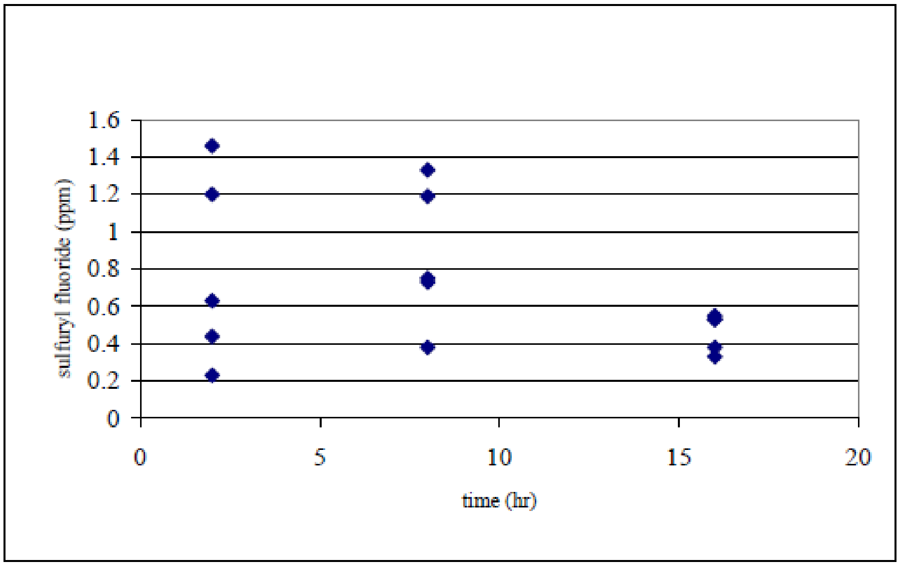
Phase two involved five replicate fumigations (20-hour exposure period) performed at one furnished home in Maxwell, CA (Colusa County) in September 2000 according to a modified aeration procedure denoted "Stack" plan. The main difference between the

TRAP and Stack plan was the method of active aeration and the timing of tarpaulin removal. TRAP involves tarpaulin removal after 10 minutes of active ventilation through a plastic duct (secured at roof line) followed by approximately 60 minutes of active aeration. The home is then closed until the following morning at which time it was tested for clearance (i.e., sulfuryl fluoride level not greater than 5 ppm). The Stack plan involved 12 hours of active ventilation through an exhaust stack (unspecified) with the tarpaulin in place except for a small opening on the side opposite the exhaust fan to allow fresh air under the tarp. After 12 hours, the tarpaulin was removed and the home was tested for clearance.

At the Maxwell site, sampling devices were placed at 5, 10, 25 and 50 feet on north, south, east and west sides of the structure. Two additional sampling devices were placed at 5 and 10 feet from the structure's four corners for a total of 24 sampling devices. It is not certain whether distances greater than 50 feet north/south/east/west or greater than 10 feet from the structure's corners had detectable sulfuryl fluoride in ambient air. Also, no monitoring was performed inside of structures adjacent to or downwind from the fumigation. Duration of each sampling period varied between 1 and 8 hours depending upon the phase of the fumigation: 1) Sampling periods 1 and 2-3 spanned 4 and 8 hours, respectively, during the 20-hour application phase; 2) Sampling periods 4-7 and 8-9 spanned 1 and 4 hours, respectively, during the 12-hour Stack aeration phase; and 3) Sampling periods 10-11 and 12 spanned 4 and 8 hours, respectively, during the 16 hours of post-clearance monitoring. For purposes of this exposure assessment, time-weighted averages for the highest sulfuryl fluoride concentrations detected among the 24 sampling devices during a given sampling period within a replicate (Figures 6 and 7) were used in estimating bystander exposure (Tables 14a,b and 16a,b). Air samples were collected onto charcoal tubes similar to the collection methods used in the worker and residential monitoring studies cited previously (Contardi and Lambesis, 1996 and Shurdut, 1995, respectively). Also similar to the worker and residential studies, Wright *et al*. (2003) did not measure back sections of all samples. Samples collected during phase two were corrected for background and an analytical recovery of 83%.

Although it is anticipated that bystander exposure during the fumigant application phase would be less than that during the aeration phase, the Maxwell data for sampling periods 1-3 (Wright *et al*., 2003) were used to estimate bystander exposure, at a submaximal application rate, during the application phase (Table 14a). As depicted in Figure 6, there are detectable levels of sulfuryl fluoride in air surrounding a structure during the entire application phase, with peak levels during the first 12 hours. Assuming neighboring indoor and outdoor sulfuryl fluoride air levels are equal (for lack of data), bystanders are potentially exposed during the entire application. Therefore, acute and short-term bystander exposures during the application phase (Tables 14a and 14b) were calculated using an upperbound sulfuryl fluoride concentration (95^{th} percentile based on the highest time-weighted sulfuryl fluoride concentration detected during sampling periods 1-2 and 1-3, respectively) and an exposure duration of 12 and 24 hours/day, respectively. Theoretically, it is possible for the four homes on each of the sides of the fumigated structure to also be fumigated in the same year. However, there are a number of factors (including economic considerations) that make more home fumigations in the same area unlikely. Since it is not likely an individual will be exposed to more than one neighboring fumigation per year, annual exposures were based on one exposure per year; since that one exposure may be at the upperbound sulfuryl fluoride air concentration, annual exposures were estimated using the 95th percentile and 24-hour exposure duration (Tables 14a and 14b). Since the application rate is expected to affect the level of gas potentially escaping from the sealed structure, the estimates derived from an application rate of 16 oz/1,000 ft^3 (16 g/m^3; Table 14a) were multiplied by a factor of 10 to estimate potential exposure at a maximal application rate of 160 oz/1,000 ft^3 (160 g/m^3; Table 14b).

Figure 8: Sulfuryl fluoride air concentrations surrounding a home during the application phase of a structural fumigation. [a]



[a] Data derived from ambient air sampling during a sulfuryl fluoride structural fumigation, at 16 oz/1000ft^3 (16 g/m^3), conducted by Wright *et al*. (2003). Time-weighted average representing the highest sulfuryl fluoride air concentration detected among 24 sampling devices were plotted against the application start time (study sampling periods 1-3; 5 replicates). The application phase duration was 20 hours. The data indicate measurable leakage of sulfuryl fluoride from treated homes during the application phase.

Table 14a. Sulfuryl fluoride exposure estimates for bystanders to a structural fumigation site during the application phase: Submaximal application rate. [a]

Bystander to structural fumigation site	Acute (12-hr) ADD [b]	Acute (24-hr) ADD [c]	Annual ADD [d]	Lifetime average ADD [e]
years old	mg/kg/day			
< 1	0.36	0.50	0.0014	-
1-2	0.31	0.43	0.0012	-
3-5	0.28	0.39	0.0010	-
6-8	0.23	0.33	0.0009	-
9-11	0.22	0.32	0.0009	-
12-14	0.17	0.23	0.0006	-
15-18	0.14	0.20	0.0006	-
adult	0.17	0.24	0.0007	0.0002

[a] Derived from chemical-specific ambient air monitoring data from phase two (Maxwell, CA) structural fumigations provided in Wright *et al*., 2003. Study investigators corrected samples for background and an analytical recovery of 83%. The application rate of 16 oz/1000 ft^3 (16 g/m^3) was considered to be 10x below the maximal level. Estimates apply to both genders within an age group.

[b] Acute (12-hr) ADD, absorbed daily dosage, was estimated to be the daily sulfuryl fluoride exposure that may occur during the first 12 hours of the application phase (see Figure 6), calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile of sulfuryl fluoride concentration as derived from Wright *et al*. (2003) ambient air monitoring during the Maxwell application phase. The 95th percentile was calculated as a 12-hour time weighted average, equal to 1.60 ppm, based on the highest level of sulfuryl fluoride collected (~ 24 liter samples) during periods 1 and 2 in each of 5 Maxwell replicates. Exposure was assumed to occur during indoor or outdoor activities for a 12-hour duration; default inhalation rates and body weights are found in Table 8.

[c] Acute (24-hr) ADD, absorbed daily dosage, was estimated to be the daily sulfuryl fluoride exposure that may occur during the entire application phase (up to 24 hours/day), and calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile of sulfuryl fluoride concentration as derived from Wright *et al*. (2003) ambient air monitoring during the Maxwell application phase. The 95th percentile was calculated as a 24-hour time weighted average, equal to 1.12 ppm, based on the highest level of sulfuryl fluoride collected (~ 24 liter samples) during periods 1-3 in each of 5 replicates of the Maxwell application phase. Exposure was assumed to occur during indoor or outdoor activities for a 24-hour duration; default inhalation rates and body weights are found in Table 8.

[d] Annual ADD, absorbed daily dosage, is the estimated daily exposure resulting from bystander exposure during outdoor activities amortized for one year. Since bystanders were assumed to be exposed to only one fumigation per year and that one fumigation may be at the highest level of exposure, the annual ADD was calculated from the short-term ADD multiplied by 1 day/year (exposure frequency) divided by 365 days.

[e] Lifetime average ADD, absorbed daily dosage. Since it is not expected that individuals would be exposed to the highest sulfuryl fluoride level every year, the average sulfuryl fluoride air concentration detected (i.e., mean of 24-hr time weighted averages of the highest level of sulfuryl fluoride detected during periods 1-3 in each of 5 replicates of the Maxwell application phase) during the application phase was used, i.e., 0.69 ppm, and an average duration of exposure (Table 8; indoor+outdoor hr/day). Adult lifetime average ADD was calculated as 1 exposure/year during adulthood (57 years) and amortized over a 75-year lifetime.

Table 14b. Sulfuryl fluoride exposure estimates for bystanders to a structural fumigation site during the application phase: Maximal application rate. [a]

Bystander to structural fumigation site	Acute (12-hr) ADD [b]	Acute (24-hr) ADD [c]	Annual ADD [d]	Lifetime average ADD [e]
years old	mg/kg/day			
< 1	3.6	5.0	0.014	-
1-2	3.1	4.3	0.012	-
3-5	2.8	3.9	0.010	-
6-8	2.3	3.3	0.009	-
9-11	2.2	3.2	0.009	-
12-14	1.7	2.3	0.006	-
15-18	1.4	2.0	0.005	-
adult	1.7	2.4	0.007	0.002

[a] Derived from chemical-specific ambient air monitoring data from phase two (Maxwell, CA) structural fumigations provided in Wright *et al*., 2003. Study investigators corrected samples for background and an analytical recovery of 83%. Since the study was performed at an application rate of 16 oz/1000 ft^3, a factor of 10x was applied to the air concentrations reported to approximate exposure at a maximal rate, 160 oz/1,000 ft^3 (160 g/m^3; Fan and Walters, 2003). Estimates apply to both genders within an age group.

[b] Acute (12-hr) ADD, absorbed daily dosage, was estimated to be the daily sulfuryl fluoride exposure that may occur during the first 12 hours of the application phase (see Figure 6), calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile of sulfuryl fluoride concentration as derived from Wright *et al*. (2003) ambient air monitoring during the Maxwell application phase. The 95th percentile was calculated as a 12-hour time weighted average, equal to 1.60 ppm based on the highest level of sulfuryl fluoride collected (~ 24 liter samples) during periods 1 and 2 in each of 5 Maxwell replicates, then multiplied by 10 to estimate exposure from maximal application rate. Exposure was assumed to occur during indoor or outdoor activities for a 12 hour-duration; default inhalation rates and body weights are found in Table 8.

[c] Acute (24-hr) ADD, absorbed daily dosage, was estimated to be the daily sulfuryl fluoride exposure that may occur during the entire application phase (up to 24 hours/day), and calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile of sulfuryl fluoride concentration as derived from Wright *et al*. (2003) ambient air monitoring during the Maxwell application phase. The 95th percentile was calculated as a 24-hour time weighted average, equal to 1.12 ppm, based on the highest level of sulfuryl fluoride collected (~ 24 liter samples) during periods 1-3 in each of 5 replicates of the Maxwell application phase, then multiplied by 10 to estimate exposure from maximal application rate. Exposure was assumed to occur during indoor or outdoor activities for a 24-hour duration; default inhalation rates and body weights are found in Table 8.

[d] Annual ADD, absorbed daily dosage, is the estimated daily exposure resulting from bystander exposure during outdoor activities amortized for one year. Since bystanders were assumed to be exposed to only one fumigation per year and that one fumigation may be at the highest level of exposure, the annual ADD was calculated from the short-term ADD multiplied by 1 day/year (exposure frequency) divided by 365 days.

[e] Lifetime average ADD, absorbed daily dosage. Since it is not expected that individuals would be exposed to the highest sulfuryl fluoride level every year, the average sulfuryl fluoride air concentration detected (i.e., mean of 24-hr time weighted averages of the highest level of sulfuryl fluoride detected during periods 1-3 in each of 5 replicates of the Maxwell application phase) during the application phase times 10x was used, i.e., 0.69 x 10 ppm, and an average duration of exposure (Table 8; indoor+outdoor hr/day). Adult lifetime average ADD was calculated as 1 exposure/year during adulthood (57 years) and amortized over a 75-year lifetime.

Data from Wright *et al*. (2003) phase one ambient air sampling during aeration according to TRAP would best represent sulfuryl fluoride air concentrations potentially encountered by any bystanders during this fumigation stage. Sulfuryl fluoride was only detectable in air surrounding the fumigated home during the first 2 hours of the TRAP aeration. The average ambient air concentration during the first hour of TRAP aeration was 12 ppm, however, the sampling consisted of only 2 replicates which is not adequate to provide 95th percentile or average exposures (DiPaolo and Frank, 2003). Therefore, bystander exposure during TRAP aeration was estimated using the sulfuryl fluoride air concentrations reported by Contardi and Lambesis (1996) for workers during general detarping activities (Table 6). Tables 15a and 15b provide bystander exposure estimates during aeration of a fumigated structure treated at submaximal and maximal application rates, respectively.

Table 15a. Sulfuryl fluoride exposure estimates for bystanders to a structural fumigation during the aeration phase using TRAP: Submaximal application rate. [a]

Bystander to structural fumigation site	Acute (2-hr) ADD [b]	Annual ADD [c]	Lifetime average ADD [d]
years old	----------------------------------	mg/kg/day	---------------------------------
< 1	0.90	0.003	-
1-2	0.78	0.002	-
3-5	0.70	0.002	-
6-8	0.58	0.002	-
9-11	0.56	0.001	-
12-14	0.41	0.001	-
15-18	0.36	0.001	-
adult	0.43	0.001	0.0002

[a] TRAP, Tarpaulin Removal and Aeration Plan, TRAP, is standard aeration practice in California (Gibbons, 1995). For lack of adequate chemical-specific ambient air monitoring during the aeration phase using TRAP (DiPaolo and Frank, 2003), the bystander exposure was estimated using sulfuryl fluoride air concentrations derived from Contardi and Lambesis (1996) monitoring of structural fumigation workers during general detarping activities (Table 6) following a submaximal sulfuryl fluoride fumigation (11 oz/1,000 ft^3 or 11 g/m^3). Estimates represent both genders within an age group.

[b] Acute (2-hr) ADD, absorbed daily dosage, is the daily sulfuryl fluoride exposure that may occur during the first 2 hours of aeration and calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95^{th} percentile of sulfuryl fluoride concentration as measured from personal air monitoring during general detarping (24 ppm, Table 6). This value was used since it was the greatest sulfuryl fluoride air level monitored, and the bystander exposure level should not exceed that of the greatest level experienced by fumigation workers. Exposure was assumed to occur during outdoor activities [2 hours based on the dissipation of sulfuryl fluoride reported by Wright *et al*. (2003) and evaluated by DiPaolo and Frank (2003)], and the default breathing rates and body weights are provided in Table 8.

[c] Annual ADD, absorbed daily dosage, is the estimated daily exposure resulting from bystander exposure during outdoor activities amortized for one year. Since bystanders were assumed to be exposed to only one fumigation per year and that one fumigation may be at the highest level of exposure, the annual ADD was calculated from the short-term ADD multiplied by 1 day/year (exposure frequency) divided by 365 days.

[d] Lifetime average ADD, absorbed daily dosage, is equal to the annual average assuming that exposure occurs once every year during one's lifetime, and calculated as 1 exposure/year during adulthood (57 years) and amortized over a 75-year lifetime. (Estimate based on an average sulfuryl fluoride air concentration of 6.2 ppm, Table 6 for general detarping activity.)

Table 15b. Sulfuryl fluoride exposure estimates for bystanders to a structural fumigation site during the aeration phase using TRAP: Maximal application rate. [a]

Bystander to structural fumigation site	Acute (2-hr) ADD [b]	Annual ADD [c]	Lifetime average ADD [d]
years old	mg/kg/day		
< 1	13.1	0.04	-
1-2	11.3	0.03	-
3-5	10.2	0.03	-
6-8	8.4	0.02	-
9-11	8.1	0.02	-
12-14	6.0	0.02	-
15-18	5.2	0.01	-
adult	6.2	0.02	0.003

[a] TRAP, Tarpaulin Removal and Aeration Plan, TRAP, is standard aeration practice in California (Gibbons, 1995). For lack of adequate chemical-specific ambient air monitoring during the aeration phase using TRAP (DiPaolo and Frank, 2003), the bystander exposure was estimated using sulfuryl fluoride air concentrations derived from Contardi and Lambesis (1996) monitoring of structural fumigation workers during general detarping activities (Table 6). Since this study was performed with an average application rate of 11 oz/1,000 ft^3 (11 g/m^3), the air concentration reported for general detarping was multiplied by 14.5 to estimate exposure associated with aeration of a structure treated at the maximal rate (160 oz/1,000 ft^3 or 160 g/m^3; Fan and Walters, 2003). Estimates represent both genders within an age group.

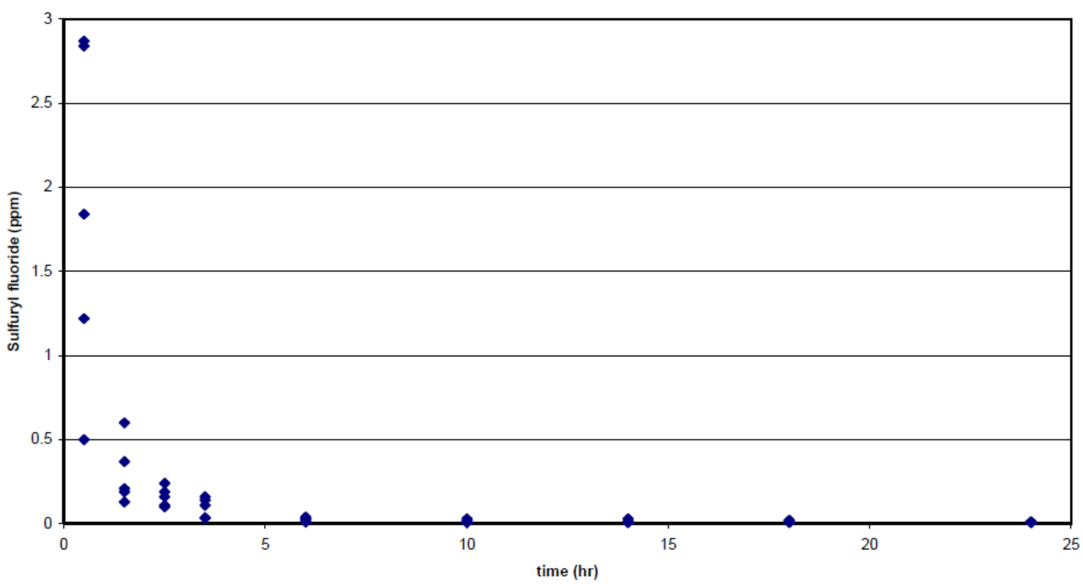
[b] Acute (2-hr) ADD, absorbed daily dosage, is the daily sulfuryl fluoride exposure that may occur during the first 2 hours of aeration and calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile of sulfuryl fluoride concentration as measured from personal air monitoring during general detarping (24 x 14.5 ppm, Table 6). This value was used since it was the greatest sulfuryl fluoride air level monitored, and the bystander exposure level should not exceed that of the greatest level experienced by fumigation workers. Exposure was assumed to occur during outdoor activities [2 hours based on the dissipation of sulfuryl fluoride reported by Wright *et al*. (2003) and evaluated by DiPaolo and Frank (2003)], and the default breathing rates and body weights are provided in Table 8.

[c] Annual ADD, absorbed daily dosage, is the estimated daily exposure resulting from bystander exposure during outdoor activities amortized for one year. Since bystanders were assumed to be exposed to only one fumigation per year and that one fumigation may be at the highest level of exposure, the annual ADD was calculated from the short-term ADD multiplied by 1 day/year (exposure frequency) divided by 365 days.

[d] Lifetime average ADD, absorbed daily dosage, is equal to the annual average assuming that exposure occurs once every year during one's lifetime, and calculated as 1 exposure/year during adulthood (57 years) and amortized over a 75-year lifetime. (Estimate based on an average sulfuryl fluoride air concentration of 6.2 x 14.5 ppm, Table 6 for general detarping activity.)

Phase two of Wright *et al*. (2003) (5 replicates) employed an alternate aeration procedure, Stack plan, which is not currently used in California. The Stack plan utilizes a 12-hour active aeration prior to removing the tarpaulin and clearance. Although not reflective of current California bystander exposure potential during aeration, phase two data (intervals 4-7) may be used to estimate exposure during the Stack aeration procedure. As depicted in Figure 7, there are detectable levels of sulfuryl fluoride in air surrounding a structure during the entire Stack aeration phase, with peak levels during the first 1-4 hours. Assuming neighboring indoor and outdoor sulfuryl fluoride air levels are equal (for lack of data), bystanders are potentially exposed during the entire stack aeration, with greatest exposure during the first 4 hours. Tables 16a and 16b present bystander exposure estimates associated with submaximal and maximal application rates, respectively. While not reflective of current California exposures, such estimates from Stack aeration may be useful in the event that bystander exposures during TRAP need to be mitigated.

Figure 9: Sulfuryl fluoride air concentrations surrounding a home during the aeration phase of a structural fumigation using the "Stack" plan. [a]



[a] Data derived from ambient air sampling during a sulfuryl fluoride structural fumigation, at 16 oz/1000ft^3 (16 g/m^3) conducted by Wright *et al*. (2003). Time-weighted averages representing the highest sulfuryl fluoride air concentration detected among 24 sampling devices were plotted against the Stack aeration start time. The Stack aeration was 12 hours; then tarps were removed and the structure was cleared. Sampling continued for 16 hours following tarpaulin removal.

Table 16a. Sulfuryl fluoride exposure estimates for bystanders to a structural fumigation site during the aeration phase using Stack plan [a]: Submaximal application rate. [b]

Bystander to structural fumigation site	Acute (1-hr) ADD [c]	Acute (4-hr) ADD [d]	Annual ADD [e]	Lifetime average ADD [f]
years old	mg/kg/day			
< 1	0.14	0.15	0.0004	-
1-2	0.12	0.13	0.0004	-
3-5	0.11	0.12	0.0003	-
6-8	0.09	0.10	0.0003	-
9-11	0.09	0.09	0.0002	-
12-14	0.06	0.07	0.0002	-
15-18	0.05	0.06	0.0002	-
adult	0.07	0.07	0.0002	0.00005

[a] Stack plan, aeration procedure used by Wright *et al*. (2003) during the definitive phase of a sulfuryl fluoride ambient air monitoring study, however, not routinely performed in California (DiPaolo and Frank, 2003). Although not reflective of current bystander exposure potential in California, the highest sulfuryl fluoride air concentration detected during Stack (5 replicates) was used to calculate the 95th percentile and average sulfuryl fluoride air concentration to which bystanders may be exposed during indoor or outdoor activities. Estimates are for both genders within an age group.

[b] Submaximal refers to a treatment below the maximum application rate (160 oz/1,000 ft^3 or 160 g/m^3; Fan and Walters, 2003). Estimates presented are from data provided by Wright *et al*. (2003) using an application rate of 16 oz/1000 ft^3 (16 g/m^3) and an 20-hr exposure period.

[c] Acute (1-hr) ADD, absorbed daily dosage, is the daily sulfuryl fluoride exposure during the first hour of aeration using the Stack method (See Figure 7) calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile (7.33 ppm) of the sulfuryl fluoride ambient air concentration, as calculated from the highest readings from each of 5 replicates during sampling interval 4 at the Maxwell site. An 1-hour exposure duration and default breathing rates and body weights (Table 8) were used.

[d] Acute (4-hr) ADD, absorbed daily dosage, is the daily sulfuryl fluoride exposure during the first 4 hours of aeration using the Stack method calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile (1.97 ppm) of the sulfuryl fluoride ambient air concentration as calculated from the highest readings from each of 5 replicates during sampling intervals 4-7 at the Maxwell site. Exposure was assumed to occur for 4 hours; default duration of exposure, breathing rates and body weights are provided in Table 8.

[e] Annual ADD, absorbed daily dosage, is the estimated daily exposure resulting from bystander exposure during indoor or outdoor activities amortized for one year. Since bystanders were assumed to be exposed to only one fumigation per year and that one fumigation may be at the highest level of exposure, the annual ADD was calculated from the short-term ADD (4-hour exposure) multiplied by 1 day/year (exposure frequency) divided by 365 days.

[f] Lifetime average ADD, absorbed daily dosage, is equal to the annual average assuming that exposure occurs once every year during one's lifetime, and calculated as 1 exposure/year during adulthood (57 years) and amortized over a 75-year lifetime. The annual average ADD was estimated as in footnote *d*, except using an average sulfuryl fluoride concentration of 0.60 ppm, rather than the 95th percentile.

Table 16b. Sulfuryl fluoride exposure estimates for bystanders to a structural fumigation site during the aeration phase using Stack plan [a]: Maximal application rate. [b]

Bystander to structural fumigation site	Acute (1-hr) ADD [c]	Acute (4-hr) ADD [d]	Annual ADD [e]	Lifetime average ADD [f]
years old	mg/kg/day			
< 1	1.4	1.5	0.0041	-
1-2	1.2	1.3	0.0036	-
3-5	1.1	1.2	0.0033	-
6-8	0.9	1.0	0.0028	-
9-11	0.9	0.9	0.0027	-
12-14	0.6	0.7	0.0019	-
15-18	0.5	0.6	0.0016	-
adult	0.7	0.7	0.0019	0.0005

[a] Stack plan, aeration procedure used by Wright *et al*. (2003) during the definitive phase of a sulfuryl fluoride ambient air monitoring study, however, not routinely performed in California (DiPaolo and Frank, 2003). Although not reflective of current bystander exposure potential in California, the highest sulfuryl fluoride air concentration detected during Stack (5 replicates) was used to calculate the 95th percentile and average sulfuryl fluoride air concentration to which bystanders may be exposed during indoor or outdoor activities. Estimates are for both genders within an age group.

[b] Maximal refers to a treatment at the maximum application rate of 160 oz/1000 ft^3 (160 g/m^3; Fan and Walters, 2003). Since Wright *et al*. (2003) used an application rate of 16 oz/1,000 ft^3 (16 g/m^3), sulfuryl fluoride air concentrations were multiplied by a factor of 10 to estimate exposure at the maximal rate.

[c] Acute (1-hr) ADD, absorbed daily dosage, is the daily sulfuryl fluoride exposure during the first hour of aeration using the Stack method (See Figure 7) calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile (7.33 ppm x 10) of the sulfuryl fluoride ambient air concentration, as calculated from the highest readings from each of 5 replicates during sampling interval 4 at the Maxwell site. An 1-hour exposure duration and default breathing rates and body weights (Table 8) were used.

[d] Acute (4-hr) ADD, absorbed daily dosage, is the daily sulfuryl fluoride exposure that may occur during the first 4 hours of aeration using the Stack method, calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with the 95th percentile (1.97 ppm x 10) of the sulfuryl fluoride ambient air concentration as calculated from the highest readings from each of 5 replicates during sampling intervals 4-7 at the Maxwell site. Exposure was assumed to occur for 4 hours; default duration of exposure, breathing rates and body weights are provided in Table 8.

[e] Annual ADD, absorbed daily dosage, is the estimated daily exposure resulting from bystander exposure during indoor or outdoor activities amortized for one year. Since bystanders were assumed to be exposed to only one fumigation per year and that one fumigation may be at the highest level of exposure, the annual ADD was calculated from the short-term ADD (4-hour exposure) multiplied by 1 day/year (exposure frequency) divided by 365 days.

[f] Lifetime average ADD, absorbed daily dosage, is equal to the annual average assuming that exposure occurs once every year during one's lifetime, and calculated as 1 exposure/year during adulthood (57 years) and amortized over a 75-year lifetime. The annual average ADD was estimated as in footnote *d*, except using an average sulfuryl fluoride concentration of 0.60 ppm x 10, rather than the 95th percentile.

For non-worker bystanders proximal to nonfood commodity fumigation sites, exposure may occur during the application and aeration phases of the fumigation. Sulfuryl fluoride is not commonly used to fumigate nonfood commodities (Table 2). Nonfood commodity fumigations are conducted by licensed applicators on a “needs basis”, as in furniture that is discovered by inspectors to be contaminated. Compliance with county, State and Federal fumigation requirements is monitored by the County Agricultural Commissioners. Only short-term and annual exposures were assessed for bystanders to nonfood commodity fumigation. However, if in the future this nonfood commodity use increases, this exposure scenario will need to be reevaluated.

No air monitoring data are available for the nonfood commodity fumigation scenario described above. Structural fumigations would be expected to generate greater bystander exposures than nonfood commodity fumigations because of the volumes used. The highest reported air concentration of sulfuryl fluoride during structural fumigations was 3 ppm (Figures 8,9). In estimating potential acute bystander exposures for nonfood commodity fumigation, a maximum air concentration of 5 ppm was assumed (Table 17). This is also the maximum air concentration allowed by the label for workers not wearing SCBA. Thus, 5 ppm is assumed to be the highest potential acute exposure. On the basis of the usages covered by the Vikane label, repetitive bystander exposure is not considered to be a significant issue. However, an expansion of uses to include food commodity fumigation may lead to higher and more frequent exposures to sulfuryl fluoride. This could produce greater exposures than those calculated in this exposure assessment document. This prospect should be considered in the regulation of current and futures uses of sulfuryl fluoride.

Table 17. Sulfuryl fluoride exposure estimates for bystanders near a nonfood commodity fumigation site. [a]

Bystander to structural fumigation site	Acute (24-hr) ADD [b]	Annual ADD [c]	Lifetime average ADD [d]
years old	---------------------------------- mg/kg/day	---------------------------------	
< 1	2.3	0.0063	-
1-2	1.9	0.0052	-
3-5	1.8	0.0049	-
6-8	1.5	0.0041	-
9-11	1.4	0.0038	-
12-14	1.0	0.0027	-
15-18	0.9	0.0025	-
adult	1.1	0.0030	0.002

[a] Since no direct air monitoring was available for these scenarios, 5 ppm, the maximum level allowed by the Vikane label, was used as the sulfuryl fluoride air concentration indoor or outdoor. Estimates are for both genders within the age group.

[b] Acute (24-hr) ADD, absorbed daily dosage, is the daily sulfuryl fluoride exposure calculated using Equations 4 and 5 (as in Table 13 footnote *b*) with an air concentration of 5 ppm sulfuryl fluoride rather than a 95th percentile since no data were available. Exposure was estimated assuming a 24-hour exposure duration and default inhalation rates and body weights found in Table 8.

[c] Annual ADD, absorbed daily dosage, is the estimated daily exposure resulting from bystander exposure during indoor or outdoor activities for one year, assuming exposure occurs 1 day per year since nonfood commodity use of sulfuryl fluoride is infrequent (see Table 2), and calculated as the product of the acute ADD divided by 365 days. Acute ADD was used rather than an intermediate-term average dosage since individuals are only expected to have one exposure per year and that exposure may be at the upperbound; in this case the upperbound exposure was assumed to not exceed 5 ppm (see footnote *b*).

[d] Lifetime average ADD, absorbed daily dosage, is equal to the annual average assuming that exposure occurs once every year for adults, and calculated as 1 exposure/year during adulthood (57 years) and amortized over a 75-year lifetime.

EXPOSURE APPRAISAL

The exposure assessment process is limited by assumptions used to estimate exposure based on the limited data available for each exposure scenario. The use of health-protective factors to compensate for uncertainties may contribute to an overestimation of risk. This exposure appraisal section addresses the adequacy of the data and suggestions for improving the exposure estimates.

Ideally, residue data used to determine the active ingredient concentrations to which individuals may be exposed should be chemical-specific. Also, the data should be obtained from use at the maximal application rate. In this assessment, three chemical-specific monitoring studies were considered in determining sulfuryl fluoride air concentrations associated with a structural fumigation (Shurdut, 1995; Contardi and Lambesis, 1996; Wright *et al*., 2003). The reported air concentrations were used to estimate upperbound and average sulfuryl fluoride exposures for workers, bystanders and residents. None of the studies were conducted at the maximal application rate allowed by the label for treatment of powder post or death watch beetles (i.e., 160 oz/1,000 ft^3 [160 g/m^3] at 20-hr exposure; Fan and Walters, 2003). It is expected that potential worker and bystander exposure during the application and opening/aeration phases of a fumigation would be dependent upon the application rate. Therefore, estimates for workers and bystanders based on sulfuryl fluoride concentrations reported by Contardi and Lambesis (1996) and Wright *et al.* (2003) were considered submaximal; maximal exposures were assumed to be 15x and 10x the submaximal values, respectively. These multiplication factors are likely an overestimate; therefore, future studies should be conducted at rates to treat for powder post beetles and not termites. While the time required to clear a structure would depend upon the application rate, sulfuryl fluoride air concentrations following clearance are not expected to depend on it. Therefore, the data from Shurdut (1995), based on fumigations at an average application rate of 14 oz/1,000 ft^3 (14 g/m^3), were considered maximal when considering residential reentry exposures. A final consideration in evaluating the studies was method recovery. Based on validation studies which repeatedly demonstrated that the analytical method underestimated the level of sulfuryl fluoride collected onto charcoal (Huff and Murphy, 1995), WHS used corrected values in estimating exposures when field spike recoveries were reported to be less than 90%.

Worker exposure

Worker exposure estimates were based on personal air monitoring during task-specific activities of 1 fumigation crew from Santa Ana, CA in November 1993 and 2 crews from El Monte, CA in May 1994 (Contardi and Lambesis, 1996). For the Santa Ana crew samples, the back sections of charcoal tubes were analyzed only if more than 5 µg sulfuryl fluoride was detected in the front section. For the El Monte crew and field spike samples, the back section of charcoal tubes were analyzed only if more than 25 µg sulfuryl fluoride was detected in the front section. Field spikes prepared by crews in November or May yielded average recoveries of 95% or 102%, respectively. Therefore, field samples were not corrected for recovery in the present assessment. However, since all back sections were not analyzed, worker exposures based on these data may be underestimated.

Based on work by Bollinger and Schutz (1987), respiratory protection in the form of SCBA is assumed to afford the highest level of protection against inhalation exposure and a 10,000-fold protection factor has been applied in calculating exposure estimates in this assessment. Improper use of the respirator will result in less protection and thus an increase in exposure. If fumigators do not properly wear the SCBA, the exposure estimates presented for this group of workers during the opening phase while wearing SCBA may be underestimated (Tables 7a-b). Although no SCBA were reportedly worn during introduction of fumigant, estimates for fumigator exposure during the introduction of sulfuryl fluoride may be overestimated since a leak occurred during 1 of the 16 sampling periods. The air concentration measured during this period was nearly 7 times that of the next highest value measured for this activity. However, since leaks may occur during this activity, it is reasonable to include this sample in the estimate calculation as the potential for this exposure does exist. As mentioned previously, maximal exposures (Table 7b) were estimated from data collected during submaximal applications and may be overestimated. Future monitoring studies should address application rates to treat powder post beetles (i.e., the maximal label application rate).

Exposure of workers who handle postfumigation nonfood commodities were based on the assumption that they may be exposed to the maximum sulfuryl fluoride levels allowed by the Vikane label (5 ppm as an 8-hour TWA). Since use of sulfuryl fluoride on nonfood commodities is infrequent in California (Table 2), it was assumed that workers were exposed to this level for 8 hours/day, 1 day/year every year during a 40-year employment. This may be an underestimate of nonfood commodity handler exposure if sulfuryl fluoride use on nonfood commodities increases in the future. It should be noted that the estimated exposure of nonfood commodity handlers in the present assessment does not reflect potential exposure of food commodity handlers. If sulfuryl fluoride is approved for use in food commodity fumigations in the future, both worker and non-worker bystander exposures will need to be reevaluated.

Residential exposures

Residential exposure estimates were based on the 48-hour sampling of 7 California homes treated with an average 14 oz/1,000 ft^3 (14 g/m^3) sulfuryl fluoride for 18-24 hours (Shurdut, 1995). As mentioned above, sulfuryl fluoride air concentrations measured postclearance in this study were considered maximal in this assessment. Field samples were corrected using a recovery factor of 65% derived from the quality assurance field spike samples. Although the samples were corrected for field recovery, only the back sections of samples with more than 25 µg of sulfuryl fluoride detected in the front section (approximately 80% of samples) were analyzed. Since all back sections were not analyzed, the residential exposures based on Shurdut's data and presented in Table 13 of this assessment may be underestimated.

For the convenience of work scheduling rather than necessity for gas dissipation, it is routine practice for California fumigation companies to clear homes for reentry on the day following the initiation of aeration, rather than the minimum label requirement, i.e., 6 or 8 hours (Shurdut, 1995; Contardi and Lambesis, 1996). In the present assessment, residential reentry exposure was calculated based on residual sulfuryl fluoride air levels according to the minimal label clearance requirement, so the estimates presented in Table 13, especially the acute values, may be greater than what occurs under routine field practice. However, these estimates represent what would be allowed according to the product label.

Residential monitoring was performed for 48 hours and reported as 24-hour TWA in ppm (Shurdut, 1995). In the present assessment, the 48-hour data were used to predict upperbound (Figure 5, Table 12) and mean (Figure 4, Table 11) sulfuryl fluoride air concentrations over time following clearance. For lack of longer-term data, the predicted dissipation curves were used to estimate sulfuryl fluoride air concentration over times beyond the sampling period, as well as to estimate the potential duration of residential exposure. An exposure duration of 7 days was assumed in the present assessment to estimate short-term, annual, and lifetime exposures in Table 13. This exposure duration was based upon the tendency of both dissipation curves (Figures 4 and 5) to approach zero around day 7. However, this duration may be an overestimate if actual sulfuryl fluoride levels dissipate more rapidly than predicted, or vice versa. Therefore, data from a longer monitoring period, e.g., 7 days, would be useful in calculating a more accurate short-term, annual, and lifetime estimates.

In addition to the assumption made regarding the number of days sulfuryl fluoride air concentrations remain above zero following clearance, assumptions have also been made regarding the number of hours per day an individual spends inside a home (exposure duration), as well as the number of times a home is treated over one's lifetime (exposure frequency). If either the duration or frequency of exposure is overestimated, the lifetime exposures presented in Table 13 would be overestimates. The exposure durations for infants, children and adults used to estimate all exposures in Table 13 are based on data collected under the direction of the California Air Resources Board (Wiley *et al.*, 1991; Jenkins *et. al.*, 1992). However, the exposure frequency of once per year every year during adulthood used to estimate lifetime exposure is an assumption. Although this assumption is likely an overestimate, it is possible given the Vikane product label does not limit frequency of treatment, and the product controls but does not prevent infestations. Since there are no label restrictions directed to limiting the frequency of structural fumigation, it is prudent to consider exposure based on the duration and frequency assumed in this assessment.

In addition to continuous sampling of sulfuryl fluoride air concentrations inside homes using charcoal tubes connected to an air pump, Shurdut (1995) also performed instantaneous sulfuryl fluoride measurements using MIRAN infrared analyzers every 2-4 hours for 30 hours from the start of aeration. In 5 of the 7 homes, sulfuryl fluoride levels were nondetectable within 8 hours following the start of aeration, where the analytical limit of detection ranged from 0.4-1.1 ppm. Based on continuous sampling data with a limit of detection of ~0.02 ppm (assuming 24 L volume), detectable sulfuryl fluoride, in the range of 0.05-0.5 ppm, remains in the air of 6 of the 7 homes at the end of the 48-hour monitoring period (54 hours following the start of aeration). Thus, instantaneous measures may create a misperception that there is no longer a potential for exposure to sulfuryl fluoride at a time sooner than actually exists. Any future air monitoring should employ continuous sampling (charcoal tubes) in multiple sites within the home. If the charcoal tube method described by Huff and Murphy (1995) is used, a maximum air flow rate of 100 ml/minute and sampling duration of 4 hours should be used, and both front and back tubes should be assayed to determine breakthrough.

Bystander exposure

Ambient air monitoring data provided by Wright *et al*. (2003) were used in estimating bystander exposure during the application phase (Tables 14a-b) as well as the Stack plan aeration (opening) phase (Tables 16a-b) of a structural fumigation. Samples were corrected for background and an analytical recovery of 83%. However, not all sample back sections were measured, thus, the reported values used in this assessment may be underestimated. Since the monitoring was conducted during fumigations at a submaximal application rate (16 oz/1,000 ft^3 or 16 g/m^3), reported values were multiplied by a factor of 10 to estimate maximal exposures presented in Tables 14b and 16b. This may be an overestimate; thus, future studies should be conducted at a maximal application rate. Also, since the Stack plan is not current practice in California, exposures presented in Tables 16a-b do not represent expected California bystander exposure. However, these values may be considered if exposure mitigation during aeration by TRAP is found necessary upon completion of the sulfuryl fluoride risk assessment.

Due to an insufficient number of replicates performed during a TRAP aeration (phase one of Wright *et al*., 2003), bystander exposure during this period (Tables 15a-b) was estimated using sulfuryl fluoride air concentrations reported for fumigation workers while performing general detarping activities (Contardi and Lambesis, 1996). As mentioned previously, the Contardi and Lambesis study was conducted at a submaximal application rate. Thus, maximal bystander exposure (Table 15b) was estimated as a factor of 14.5x greater than the submaximal exposures (Table 15a) and may be an overestimate. Future ambient air monitoring studies should include more replicates of a TRAP aeration and should also be conducted at a maximal application rate.

Since no air monitoring data were available, adult and child bystander exposures associated with nonfood commodity fumigation were estimated assuming a maximum ambient air level of 5 ppm as allowed by the Vikane label. It was assumed that the level of sulfuryl fluoride allowed by the label would not be exceeded, as the label has the force of law.

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APPENDIX I

STRUCTURAL FUMIGATION WORKER EXPOSURE: SULFURYL FLUORIDE RECOVERY FROM FIELD SPIKES

For the worker monitoring study performed by Contardi and Lambesis (1996), quality assurance samples were prepared in the field (field spikes) on all 5 monitoring days in Santa Ana, CA and on 3 of the 5 monitoring days in El Monte, CA. Samples were prepared similarly to the method used by Huff and Murphy (1995) and Shurdut (1995). Briefly, charcoal tubes, in duplicate for blanks and in triplicate for each of 2 fortification levels at each site, were connected to a battery-operated pump with a flow rate of either 50 or 100 ml/min, and spiked with a known volume of Vikane using a gas-tight or water-plugged syringe. Field spikes were prepared in the back of a rental van at the exterminator's business then placed in a shaded area at the business or transported to the site were the worker monitoring was being conducted. Air was drawn through the tubes for approximately 4 hours at 100 ml/minute, or 8 hours at 50 ml/minute. To determine the effect of travel and storage on field samples, travel spikes were prepared the same as the field spikes, except air was drawn through travel spikes for 10-15 minutes only. Reference solutions were also prepared in the field immediately after preparation of field spikes by injecting directly into 20 ml sodium hydroxide the same volume of Vikane used to prepare the 2 field spike fortification levels.

Contardi and Lambesis (1996) extracted sulfuryl fluoride from the charcoal tubes of field spike and experimental samples by alkaline hydrolysis as previously described (Murphy and Contardi, 1994; Huff and Murphy, 1995). However, quantitation using fluoride selective electrode analysis was performed by a standard addition technique described by Murphy and Contardi (1994) rather than a fluoride standard curve (Huff and Murphy, 1995; Shurdut, 1995). Field spike analysis and recovery is listed in Table A-1. For phase 2 field spikes, an average recovery of 95% was estimated using both the 21 and 836 µg spikes since the mass of sulfuryl fluoride detected on the charcoal collection tubes of field samples was not provided in the data. For phase 3, the average recovery was estimated to be 102%. Since recovery from both phases were greater than 90%, worker field samples used to estimate values in Table 6, 7a, and 7b were not adjusted for recovery.

Table A-1. Structural fumigation worker monitoring study: Field spike analysis and recovery. [a]

	Field spike no.[b]	SF analyzed front [c]	SF analyzed back [d]	SF analyzed total [e]	SF loaded (nominal) [f]	Recovery [g]
		μg	μg	μg	μg	%
Phase 2 [h]						
	41	540	131	671	836	80.26
	42	716	55	771	836	92.22
	43	726	44	770	836	92.11
	44	20	ND [i]	20	21	95.24
	45	22	ND	22	21	104.76
	46	19	ND	19	21	90.48
	49	738	6	744	836	89.00
	50	701	68	769	836	91.99
	51	742	41	783	836	93.66
	52	23	ND	23	21	109.52
	53	20	ND	20	21	95.24
	54	21	ND	21	21	100.00
	57	738	ND	738	836	88.28
	58	715	24	739	836	88.40
	59	710	32	742	836	88.76
	60	21	ND	21	21	100.00
	61	21	ND	21	21	100.00
	62	21	ND	21	21	100.00
	65	748	12	760	836	90.91
	66	640	87	727	836	86.96
	67	683	82	765	836	91.51
	68	19	ND	19	21	90.48
	69	20	ND	20	21	95.24
	70	20	ND	20	21	95.24
	73	543	97	640	836	76.56
	74	545	119	664	836	79.43
	75	592	109	701	836	83.85
	76	25	ND	25	21	119.05
	77	25	ND	25	21	119.05
	78	25	ND	25	21	119.05
	81	25	X [j]	25	21	119.05
Arithmetic mean	Phase 2					95

Table A-1 continued…

	Field spike no.[b]	SF analyzed front[c]	SF analyzed back[d]	SF analyzed total[e]	SF loaded (nominal)[f]	Recovery[g]
	µg	µg	µg	µg	%	
Phase 3[h]	82	23	X	23	21	109.52
	83	25	X	25	21	119.05
	84	172	7.2	179.2	209	85.75
	85	183	ND	183	209	87.56
	86	200	ND	200	209	95.69
	89	25	X	25	21	119.05
	90	25	X	25	21	119.05
	91	24	X	24	21	114.29
	92	175	11	186	209	89.00
	93	180	6	186	209	89.00
	94	188	2.4	190.4	209	91.10
	97	23	X	23	21	109.52
	98	21	X	21	21	100.00
	99	25	X	25	21	119.05
	100	180	3.9	183.9	209	87.99
	101	185	19	204	209	97.61
	102	194	ND	194	209	92.82
Arithmetic mean	Phase 3					102

[a] Field spike data from Contardi and Lambesis, 1996. Field spike samples were prepared in triplicate by injecting 21, 209, and 836 µg sulfuryl fluoride onto charcoal tubes connected to an air sampling pump set at a flow rate of 50 or 100 ml/minute for 8 or 4 hours, respectively. Analysis of field spike blanks, i.e., unspiked charcoal tubes prepared in duplicate, showed no detectable sulfuryl fluoride (data not shown).

[b] Field spike identification numbers as used in Table 14 of Contardi and Lambesis (1996). Field spikes 41-80 were prepared between November 1-5, 1993 in Santa Ana, CA; field spikes 81-104 were prepared between May 3-5, 1994 in El Monte, CA.

[c] Amount of sulfuryl fluoride (SF), detected in the front section of the charcoal tube following desorption, hydrolysis, fluoride selective electrode detection, and standard addition quantitation (Contardi and Lambesis, 1996).

[d] Amount of SF detected in the back section of the charcoal tube following desorption, hydrolysis, fluoride selective electrode detection, and standard addition quantitation (Contardi and Lambesis, 1996). For El Monte samples (No. 81-104), back sections were not analyzed if 25 µg or less sulfuryl fluoride was detected on the front tube.

[e] Total amount of SF collected on charcoal tube, i.e., sum of the front and back section.

[f] SF loaded (nominal), refers to the amount of sulfuryl fluoride intended to be injected onto the tube.

[g] Recovery is equal to the total sulfuryl fluoride analyzed divided by the amount of sulfuryl fluoride loaded (nominal) times 100.

[h] Phase 2 was conducted in Santa Ana, CA, November 1-5, 1993. Phase 3 was conducted in El Monte, CA, May 9-13, 1994.

[i] ND, nondetectable.

[j] “X” indicates back sections not analyzed.

APPENDIX II

SULFURYL FLUORIDE DISSIPATION FROM AIR AFTER RESIDENTIAL STRUCTURAL FUMIGATION

Dissipation of sulfuryl fluoride from 7 different homes fumigated in California in 1994 was reported by DowElanco (Shurdut, 1995) and used to estimate residential exposure upon reentry into homes postclearance (Table 13). Starting at 0, 8, 16, 24, 32, and 40 hours postclearance, 6 consecutive 8-hour continuous air samples from 3 rooms in each home were collected onto charcoal sorbent tubes connected to an air pump with a flow rate of 50 ml/minute. As discussed previously in the "Determination of sulfuryl fluoride air concentration" section of the EXPOSURE ASSESSMENT chapter, sulfuryl fluoride air concentrations reported for the 7 homes in Tables 23-29 of Shurdut (1995) were adjusted by the present authors for a recovery of 64.6% and are provided as "corrected" sulfuryl fluoride air concentrations in Table A-2 below. This recovery value reflects the recovery calculated from quality assurance samples, referred to as field spikes, prepared at 3 of the 7 California fumigation sites (Table 6 of Shurdut, 1995) and shown below in Table A-3. Briefly, charcoal tubes connected to battery operated sampling pump with a flow rate of 50 ml/minute were spiked with a known volume of Vikane using a gas-tight syringe and air was drawn through the tubes for 8 hours. These tubes, or field spikes, were prepared inside a van or a shaded area outside the homes being monitored. Sulfuryl fluoride collected on the field spikes as well as experimental (inside home) samples were desorbed with sodium hydroxide, analyzed by fluoride ion selective electrode method and quantitated using a fluoride standard curve (Shurdut, 1995). The method used by Shurdut (1995) was comparable to that of Huff and Murphy (1995).

The average recovery of 64.6% calculated from 24 California field spike samples (Table A-3) is comparable to the average recovery of 63% calculated for reference solutions prepared in the field by injecting directly into 20 ml 0.04 N sodium hydroxide the same volume of Vikane used for field spike samples (Table 3b page 40 of Shurdut, 1995,). The sulfuryl fluoride air concentration for each home at each timepoint was calculated by averaging the concentrations determined for the 3 rooms in each home at each time point, and corrected for 64.6% recovery. These 3-room averages, considered to represent the air concentrations potentially encountered by residents reentering their homes 0-48 hours postclearance, are presented in Table 9 of this assessment.

Table A-2. Sulfuryl fluoride (SF) air concentrations in California homes following tarpaulin fumigation. [a]

House no./Rm. [b]	Monitoring period [c]	SF analyzed [d]	Sample volume [e]	Raw $[SF]_{air}$ [f]	Corrected $[SF]_{air}$ [g]
	hr	µg	L	ppm 8-hr TWA [h]	ppm 8-hr TWA
1/a	0-8	18.2	29.7	0.147	0.228
1/b	0-8	21.8	28.8	0.182	0.282
1/c	0-8	21.7	26.1	0.200	0.309
2/a	0-8	105	23.5	1.072	1.662
2/b	0-8	131	23.6	1.332	2.065
2/c	0-8	102	21.6	1.133	1.757
3/a	0-8	42.9	24.5	0.420	0.651
3/b	0-8	44.3	25.4	0.419	0.649
3/c	0-8	16.4	7.1	0.554	0.859
4/a	0-8	17.2	26.2	0.158	0.244
4/b	0-8	5.72	18.5	0.074	0.115
4/c	0-8	11	22.6	0.117	0.181
5/a	0-8	69.1	23.2	0.715	1.108
5/b	0-8	66.7	22.9	0.699	1.084
5/c	0-8	66.1	23.1	0.687	1.065
6/a	0-8	6.25	26.6	0.056	0.087
6/b	0-8	5.55	26.1	0.051	0.079
6/c	0-8	4.7	26	0.043	0.067
7/a	0-8	18	24.3	0.178	0.276
7/b	0-8	17.4	26	0.161	0.249
7/c	0-8	21.4	24.7	0.208	0.322
1/a	8-16	3.3	26.3	0.030	0.047
1/b	8-16	4.35	21.8	0.048	0.074
1/c	8-16	7.89	23.1	0.082	0.127
2/a	8-16	67.4	25.6	0.632	0.980
2/b	8-16	103	23	1.075	1.666
2/c	8-16	96.3	25.3	0.914	1.416
3/a	8-16	13	19.3	0.162	0.251
3/b	8-16	21.1	25	0.203	0.314
3/c	8-16	20.9	25.2	0.199	0.309
4/a	8-16	20.1	28.5	0.169	0.262
4/b	8-16	28.9	28.9	0.240	0.372
4/c	8-16	16.4	26.6	0.148	0.229
5/a	8-16	46.2	25.9	0.428	0.664
5/b	8-16	42.9	26.7	0.386	0.598
5/c	8-16	51.1	26	0.472	0.731

Table A-2 continued…

House no./Rm. [b]	Monitoring period [c]	SF analyzed [d]	Sample volume [e]	Raw $[SF]_{air}$ [f]	Corrected $[SF]_{air}$ [g]
	hr	µg	L	ppm 8-hr TWA [h]	ppm 8-hr TWA
6/a	8-16	1.05	26.5	0.010	0.015
6/b	8-16	1.05	23.9	0.011	0.016
6/c	8-16	1.05	22.9	0.011	0.017
7/a	8-16	13.7	25.7	0.128	0.198
7/b	8-16	15.2	26.4	0.138	0.214
7/c	8-16	12.7	23.5	0.130	0.201
1/a	16-24	3.13	27	0.028	0.043
1/b	16-24	4.43	26.6	0.040	0.062
1/c	16-24	5.63	24.9	0.054	0.084
2/a	16-24	37.2	22.4	0.399	0.618
2/b	16-24	23.1	25.2	0.220	0.341
2/c	16-24	51.6	24.1	0.514	0.797
3/a	16-24	3.17	25.6	0.030	0.046
3/b	16-24	3.26	23.9	0.033	0.051
3/c	16-24	4.55	25.9	0.042	0.065
4/a	16-24	22.1	26.3	0.202	0.313
4/b	16-24	15.5	22.7	0.164	0.254
4/c	16-24	14.9	24.1	0.148	0.230
5/a	16-24	18.2	23.7	0.184	0.286
5/b	16-24	8.01	22.7	0.085	0.131
5/c	16-24	12.3	24.8	0.119	0.185
6/a	16-24	1.05	25.7	0.010	0.015
6/b	16-24	1.05	26.2	0.010	0.015
6/c	16-24	1.05	26.3	0.010	0.015
7/a	16-24	8.36	26.3	0.076	0.118
7/b	16-24	7.37	26	0.068	0.105
7/c	16-24	5.94	23.6	0.060	0.094
1/a	24-32	2.42	26.7	0.022	0.034
1/b	24-32	3.6	27.1	0.032	0.049
1/c	24-32	3.71	24	0.037	0.058
2/a	24-32	59.3	23.5	0.606	0.939
2/b	24-32	64.4	24.9	0.621	0.962
2/c	24-32	52.9	24.4	0.520	0.807

Table A-2 continued…

House no./Rm. [b]	Monitoring period [c]	SF analyzed [d]	Sample volume [e]	Raw $[SF]_{air}$ [f]	Corrected $[SF]_{air}$ [g]
	hr	µg	L	ppm 8-hr TWA [h]	ppm 8-hr TWA
3/a	24-32	3.96	26.2	0.036	0.056
3/b	24-32	2.44	26.5	0.022	0.034
3/c	24-32	2.95	23.6	0.030	0.047
4/a	24-32	2.63	25.3	0.025	0.039
4/b	24-32	3.9	24	0.039	0.060
4/c	24-32	4.34	25.7	0.041	0.063
5/a	24-32	8.81	25.7	0.082	0.128
5/b	24-32	9.33	25.3	0.089	0.137
5/c	24-32	9.33	25	0.090	0.139
6/a	24-32	1.05	24.1	0.010	0.016
6/b	24-32	1.05	25.2	0.010	0.016
6/c	24-32	1.05	26.8	0.009	0.015
7/a	24-32	6.31	23.9	0.063	0.098
7/b	24-32	6.64	25.5	0.063	0.097
7/c	24-32	5.94	25.8	0.055	0.086
1/a	32-40	2.68	26.9	0.024	0.037
1/c [i]	32-40	2.84	31.7	0.022	0.033
2/a	32-40	66.8	25.4	0.631	0.978
2/b	32-40	69.6	23.4	0.714	1.107
2/c	32-40	79	26	0.729	1.130
3/a	32-40	4.13	25.6	0.039	0.060
3/b	32-40	6.75	23.8	0.068	0.106
3/c	32-40	5.6	24.3	0.055	0.086
4/a	32-40	9.31	28.8	0.078	0.120
4/b	32-40	6.88	24	0.069	0.107
4/c	32-40	7.14	25.4	0.067	0.105
5/a	32-40	16.2	24.3	0.160	0.248
5/b	32-40	7.81	24.1	0.078	0.121
5/c	32-40	11.1	25.6	0.104	0.161
6/a	32-40	1.05	26.7	0.009	0.015
6/b	32-40	1.05	26.7	0.009	0.015
6/c	32-40	1.05	26.8	0.009	0.015
7/a	32-40	5.15	24.3	0.051	0.079
7/b	32-40	6.12	27.4	0.054	0.083
7/c	32-40	5.23	26.2	0.048	0.074

Table A-2 continued…

House no./Rm. [b]	Monitoring period [c]	SF analyzed [d]	Sample volume [e]	Raw $[SF]_{air}$ [f]	Corrected $[SF]_{air}$ [g]
	hr	µg	L	ppm 8-hr TWA [h]	ppm 8-hr TWA
1/a	40-48	1.05	21.1	0.012	0.019
1/b	40-48	3.03	23	0.032	0.049
1/c	40-48	2.48	23.9	0.025	0.039
2/a	40-48	23.7	22.4	0.254	0.394
2/b	40-48	34.3	25.9	0.318	0.493
2/c	40-48	35.2	24	0.352	0.546
3/a	40-48	2.91	22	0.032	0.049
3/b	40-48	4.62	22.9	0.048	0.075
3/c	40-48	4.25	25.9	0.039	0.061
4/a	40-48	2.74	25.8	0.025	0.040
4/b	40-48	4.18	23.7	0.042	0.066
4/c	40-48	2.52	26.4	0.023	0.036
5/a	40-48	6.22	24.5	0.061	0.094
5/b	40-48	7.01	24.3	0.069	0.107
5/c	40-48	5.4	25.3	0.051	0.079
6/a	40-48	1.05	23.4	0.011	0.017
6/b	40-48	1.05	23	0.011	0.017
6/c	40-48	1.05	25.5	0.010	0.015
7/a	40-48	4.18	24.1	0.042	0.065
7/b	40-48	3.74	27.2	0.033	0.051
7/c	40-48	3.81	25.6	0.036	0.055

[a] Chemical-specific air monitoring data (California only) collected during the first 48 hours following minimum clearance requirements for Vikane structural fumigation, i.e., 6 hours aeration, sulfuryl fluoride air concentration ≤ 5 parts per million (ppm, Shurdut, 1995).

[b] Houses 1 – 7 correspond to houses C1 - C7 in Tables 23-29 of Shurdut, 1995. Rooms a, b, and c represent the 3 different rooms in which air pumps and collection tubes were placed during the 48 hours of air sampling in each home.

[c] Monitoring period refers to the time postclearance during which air pumps drew air across charcoal tubes which collected sulfuryl fluoride from the air in each room (clearance being time zero). Pumps were set at a flow rate of ~50 ml/minute for approximately 8 hour intervals for each sampling period.

[d] SF analyzed refers to the amount of sulfuryl fluoride on the charcoal tube as measured following alkaline hydrolysis, fluoride ion selective electrode detection, and fluoride standard curve quantitation. The field spike recovery factor has not been applied to this value.

[e] Sample volume refers to the volume of room air collected during the monitoring period as determined by the flow rate for each individual pump and duration of pump flow.

Table A-2 footnotes continued…

[f] Raw $[SF]_{air}$ refers to the sulfuryl fluoride air concentration prior to recovery correction, expressed as an 8-hour time weighted average (TWA, see footnote *i* below), and calculated as follows:

Raw SF (ppm) = [(SF analyzed / sample volume) x 24.5 L] / 102.07

where: 24.5 L is the volume of 1 mole of sulfuryl fluoride at 25 °C
102.07 is the molecular weight of sulfuryl fluoride

[g] Corrected $[SF]_{air}$ refers to the sulfuryl fluoride air concentration corrected by a factor of 1.55 based on the field spike average recovery of 64.6% (Table A-3), and calculated by multiplying Raw $[SF]_{air}$ by 1.55.

[h] ppm 8-hr TWA, parts per million 8-hour Time Weighted Average. This value is equal to the amount of sulfuryl fluoride detected on the charcoal tube (as collected over an 8-hour time period) divided by the total volume of air collected during the 8-hour period.

[i] There were no sulfuryl fluoride air monitoring data provided for House 1, Room b for sampling period 32-40 hours postclearance due to a reported pump malfunction (Shurdut, 1995).

Table A-3. Sulfuryl fluoride (SF) recovery from field spike samples prepared for experimental monitoring of postclearance SF air concentrations in fumigated homes. [a]

Sample ID [b]	Amount SF spiked [c]	Amount SF analyzed [d]	SF recovery [e]
	µg	µg	%
VIK-C9-3	20.9	13.8	66.0
VIK-C9-4	20.9	13.1	62.7
VIK-C9-5	20.9	12.8	61.2
VIK-C9-6	20.9	12	57.4
VIK-C9-7	209	146	69.9
VIK-C9-7 [f]	209	139	66.5
VIK-C9-9	209	149	71.3
VIK-C9-10	209	141	67.5
VIK-C9-13	20.9	12.9	61.7
VIK-C9-14	20.9	12.2	58.4
VIK-C9-15	20.9	13.2	63.2
VIK-C9-16	20.9	12.8	61.2
VIK-C9-17	209	117	56.0
VIK-C9-18	209	111	53.1
VIK-C9-19	209	125	59.8
VIK-C9-20	209	122	58.4
VIK-C9-25	209	133	63.6
VIK-C9-26	209	149	71.3
VIK-C9-27	209	152	72.7
VIK-C9-28	209	149	71.3
VIK-C9-21	20.9	13.5	64.6
VIK-C9-22	20.9	14.6	69.9
VIK-C9-23	20.9	14.9	71.3
VIK-C9-24	20.9	14.8	70.8
Average [g]			64.6

[a] Field spike samples were prepared in a van or shady area outside of the homes being monitored on 3 separate days in California. Briefly, a known volume of Vikane (99.8% sulfuryl fluoride) was injected onto a charcoal tube connected to a battery operated sampling pump calibrated to a flow rate of ~50 ml/minute. Air was drawn through the field spikes for ~8 hours then handled in the same manner as the experimental samples. (Shurdut, 1995)

[b] Sample ID refers to the field spike sample identifications used in Table 6 of Shurdut, 1995.

[c] Amount SF spiked refers to that amount of sulfuryl fluoride delivered to the field spikes based on the volume of the injection applied.

[d] Amount SF analyzed refers to the amount of sulfuryl fluoride measured for each field spike following alkaline hydrolysis, fluoride selective electrode detection, and fluoride standard curve quantitation.

Table A-3 footnotes continued…

[e] SF recovery refers to the percentage of sulfuryl fluoride delivered to field spikes that was detected using the analytical procedure described in footnote *d* and calculated as follows:

Recovery (%) = Amount SF analyzed / Amount SF spiked x 100

[f] "VIK-C9-7" was repeated twice in Table 6 of Shurdut, 1995. For the present assessment, the repeat was assumed to be an error and that VIK-C9-8 was intended.

[g] Average recovery is the arithmetic means of the 24 field spike sample recoveries. This value was used to calculate the correction factor for experimental samples given in Tables A-2. This value is the same as estimated in the study using 2 correction values, 90.6% for the analytical method and 71% for the field spikes (0.901 x 0.71).

APPENDIX III

SULFURYL FLUORIDE STUDY SUMMARIES

Worker exposure air monitoring

1) As part of the federal reregistration of sulfuryl fluoride, the Dow Chemical Company submitted a worker exposure study, "Amended report for evaluation of sulfuryl fluoride exposures to workers during structural fumigations when using Vikane Gas Fumigant," in compliance with Good Laboratory Practice Standards (40 CFR Part 160) (Contardi and Lambesis, 1996). All sample collection practices were based upon U.S. EPA Pesticide Assessment Guidelines, Subdivision U, Applicator Exposure Monitoring (October 1986). Four work crews were monitored from 3 fumigation companies in either Florida or California, however only the California data were used in this assessment.

2) In 1987, WHS in cooperation with industry representatives conducted monitoring of structural fumigation workers during the opening phase following treatment of 9 homes in southern California to evaluate work practices and identify possible unacceptable exposure hazards (Gibbons *et al.*, 1989). Three homes were treated with methyl bromide and 6 homes were treated with sulfuryl fluoride. Personal air sampling pumps delivered samples into collection bags worn by the workers during several tasks involved in the initiation of aeration. Sulfuryl fluoride levels were immediately measured using Interscan Vikane analyzers. This pilot study identified that exposures greater than 5 ppm occurred, albeit for brief periods of time, during seam opening and tarp removal activities and proposed the need for procedure modification to decrease potential exposure. The tarpaulin removal aeration plan (Gibbons, 1995) was developed in light of this study and satisfies California regulation (3 CCR 6780 (c)) requiring employers to have a plan by which workers may safely perform their duties involving fumigants. However, these data are excluded from use in this assessment since fumigation practices have changed since the time of this study.

3) In 1989, the Florida State Departments of Agriculture, and Health and Rehabilitative Services asked NIOSH to examine health related effects due to fumigation worker exposure to methyl bromide and sulfuryl fluoride (O'Neill and Sanderson, 1991). Personal air sampling for sulfuryl fluoride was conducted according to NIOSH method 6012 (100 ml/min for 100 minutes), but the details of the worker activities performed during the sampling were unspecified. It was reported that 72.7% of the samples were below the limit of detection (7 µg sulfuryl fluoride), the highest fumigator exposure was 16.9 mg/m^3 (4 ppm) and the highest tent crew worker exposure was 12.9 mg/m^3 (3 ppm). This study was never published possibly due to problems detected with the methyl bromide sampling portion of the report. Therefore this study was excluded from use in this assessment.

Residential exposure air monitoring

1) There is only one air monitoring study in which sampling was conducted continuously according to the method of Huff and Murphy (1995). Briefly, a pump with a maximum flow rate of 100 ml/minute drew air samples into charcoal sorbent tubes. Air samples from 3 rooms of a fumigated home were collected during 8-hour intervals from 8 to 48 hours following clearance. Sulfuryl fluoride collected on the charcoal tubes was hydrolyzed with sodium hydroxide and the released fluoride ion was quantitated by an ion selective electrode. The limit of quantification reported for this method was 2.1 µg sulfuryl fluoride. A recovery of 65% was used to calculate sulfuryl fluoride concentrations in the samples as indicated in the section on exposure calculations for residents and according to Huff and Murphy (1995). In addition to the continuous charcoal sorbent tube method, MIRAN 101V units were used for instantaneous sampling, however, readings were below the level of detection of the instruments (limit of detection range 0.4-1.1 ppm) for the majority of the samples. Therefore, only continuous sampling measurements were included in the present assessment, as noted in the section on exposure calculations for residents.

Bystander exposure: ambient air monitoring during structural fumigations

Wright *et al*. (2003) submitted a sulfuryl fluoride air monitoring study intended to estimate bystander exposure during residential structural fumigation (application, aeration and postclearance phases). This data has been reviewed by DPR's Environmental Monitoring and Worker Health and Safety Branches (DiPaolo and Frank, 2003; Wofford, 2003). Briefly, air monitoring was conducted within and surrounding two homes during the application, aeration, and postclearance phases of a fumigation performed at a target dose rate of 16 oz/1000 ft^3 (16 g/m^3; i.e., 2x termite rate if 70° F, 20-hour exposure and 12-hour half-loss time). The total duration of the monitoring was 48 hours from the time of fumigant introduction, and the sampling intervals ranged from 1-8 hours. Two replicate fumigations (24-hour exposure period) were performed at one unfurnished home in Rancho Cordova, CA (Sacramento County) in May 1999 according to current California application and aeration (TRAP, Tarpaulin Removal and Aeration Plan) procedures. Five replicate fumigations (20-hour exposure period) were performed at one furnished home in Maxwell, CA (Colusa County) in September 2000, however, a modified aeration procedure, "Stack" plan, was used. The main difference between the TRAP and Stack plan was the method of active aeration and the timing of tarpaulin removal. The TRAP involved tarpaulin removal after 10 minutes of active ventilation through a plastic duct (secured at roof line) followed by approximately 60 minutes of active aeration. The home was then closed until the following morning at which time it was tested for clearance (i.e., sulfuryl fluoride level not greater than 5 ppm). The Stack plan involved 12 hours of active ventilation through an exhaust stack (unspecified) with the tarpaulin in place except for a small opening on the side opposite the exhaust fan to allow fresh air under the tarp. After 12 hours, the tarpaulin was removed and the home was tested for clearance.

Exposure estimates may be calculated based upon the data provided in the present study. For example, 9-11 year-old boys and female adults are used to represent children and adult exposures, respectively, since they are expected to have the highest exposure potentials for children and adults based on expected exposure duration (Wiley *et al.*, 1991; Jenkins *et al.*, 1992), breathing rates (Layton, 1993) and body weights (U.S. EPA, 1997). Using data from the present study's Appendix B Tables B-1 and B-2, an upperbound absorbed daily dosage for the fumigant application stage and the aeration stage were derived from the 95th percentile of sulfuryl fluoride air concentration and presented below. Unlike the study authors, the estimates provided below are based on the highest level of sulfuryl fluoride detected for a given stage, regardless of location (distance or direction), rather than an average of samples for all locations around the house at a given distance. For purposes of the estimates below, the fumigant application stage is considered to be represented by sampling periods 1-6 and 1-3 in phase one and phase two, respectively. The aeration stage is considered to be represented by sampling periods 7-13 and 4-12 in phase one and phase two, respectively.

Sulfuryl fluoride air concentrations during the first 20-24 hours of a structural fumigation (fumigant application stage) as provided in both phase one and two of the present study may be used to estimate bystander exposure during this period. For example, using 5 replicates from Table B-2 phase two, bystander children and adults would have an estimated upperbound (95th percentile) absorbed daily dosage of 8.7 and 2.8 µg sulfuryl fluoride/kg/day, respectively, during the application stage. It should be noted that since phase one and phase two monitored different houses, data from both phases should not be combined in estimating exposures during the fumigant application stage. Also, phase one was intended to be a pilot study and only provides 2 replicates.

Air samples collected during aeration using TRAP (phase one) are appropriate for estimating bystander exposure during structure aeration under current California industry practices. However, only phase one used this method and phase one, in addition to being designed as a pilot study, only provides 2 replicates which is not desirable in estimating exposures. For lack of other TRAP ambient air monitoring data, using the 2 replicates from Table B-1 phase one results in an upperbound absorbed daily dosage for children and adults during the aeration stage of 2607 and 829 µg sulfuryl fluoride/kg/day. The average absorbed daily dosage for children and adults during the aeration is 52 and 16 µg sulfuryl fluoride/kg/day, respectively. Using surrogate data based on worker monitoring during general detarping activities (Contardi and Lambesis, 1996), upperbound bystander exposure during aeration are estimated to be 3460 and 1000 µg sulfuryl fluoride/kg/day for children and adults, respectively.

Although not applicable to current California practices, data from phase two aeration using the stack method may be used to estimate bystander exposure based on a different aeration method. Using 5 replicates from Table B-2 phase two, the upperbound absorbed daily dosage for children and adults during stack aeration is estimated to be 48 and 15 µg sulfuryl fluoride/kg/day, respectively. The average absorbed daily dosage for children and adults during the stack aeration is 7.9 and 2.5 µg sulfuryl fluoride/kg/day, respectively. Although the stack aeration appears to result in lower bystander exposures, it would not be appropriate to compare estimates for the different aeration methods since phase one only has 2 replicates, and both phases use different houses.

Development of aeration protocols

1) A study was conducted in Florida in 1990, to monitor air levels of sulfuryl fluoride following clearance as allowed at that time, i.e., the Vikane label directions for aeration allowed reoccupation when the interior concentration of sulfuryl fluoride was 5 ppm or less, without requiring a minimum aeration period (Bloomcamp *et al.*, 1991; Scheffrahn *et al.*, 1992a). Considering the tight construction of modern homes and air conditioning systems which limit indoor/outdoor air exchange as well as the sorptive properties of construction and furnishing materials used in homes (Scheffrahn *et al.*, 1987a), it was thought that desorption may occur following the initial aeration to ≤ 5 ppm. Following fumigation, homes were aerated to 5 ppm or less, at which time all windows and doors were closed and ventilation systems were shut down for 2 hours. During the 2-hour closure, air levels were monitored every 30 minutes with Interscan and MIRAN 101 units. After the 2-hour closure, homes were aerated for at least 10 minutes until levels were 5 ppm or less, then homes were closed again and monitored every 30 minutes until no increase was observed between 2 readings. Results demonstrated that sulfuryl fluoride levels rise above 5 ppm during the initial closure period and the registrant suggested a revision to the aeration procedure (Bloomcamp *et al.*, 1991). Other studies following a similar protocol showed that levels may rise above 5 ppm even during the second closure period, mainly in rooms with stuffed furniture (Thoms *et al.*, 1992). Based upon these findings, a minimum aeration period of 6 or 8 hours, depending upon treatment dosage, is now incorporated into the Vikane label directions for use.

2) Studies were conducted in Florida and California in 1990 to validate proposed revisions to aeration procedures prompted by the results of the monitoring outlined above (Schneider and Bean, 1992). A minimum of 45 minutes of active aeration (with at least 1 fan) until 5 ppm or less was attained, followed by closing period of 6 or 8 hours (from time of first opening) for homes treated with ≤16 oz/1000 ft^3 or >16 oz/1000 ft^3 (16 g/m^3), respectively, then followed by a 15-minute reopening/reventilation period. Peak sulfuryl fluoride levels were attained within 2 hours post-closing for both application levels, and all homes were below 5 ppm following the final 15-minute reopening period. Further studies which monitored sulfuryl fluoride levels for 24 hours following a minimum of 1-hour active aeration and 6-hour waiting period confirmed the effectiveness of the aeration plan to ensure sulfuryl fluoride levels do not rise above 5 ppm following the time homes would be cleared for reoccupation (Bean and Sprint, 1992). Thus, the aeration instructions on the current Vikane label (2000) should ensure levels do not rise above 5 ppm following reoccupation of residential structures.

Nonfood commodity fumigation

1) Dissipation of sulfuryl fluoride from individual structural and household commodities was investigated by Scheffrahn and coworkers (Scheffrahn *et al.*, 1987a; Scheffrahn *et al.*, 1987b). Samples of 1-10 g were treated by chamber fumigation at 2 rates (36 mg/l and 360 mg/l), 10x and 100x the rate for control of drywood termites. Following aeration periods ranging from 2 hours to 40 days, headspace sulfuryl fluoride concentrations were determined by gas chromatography. Recovery from spiked samples ranged between 54-120% except for the concrete block sample which had a recovery of <1%, indicating possible alkaline hydrolysis or chemisorption. These data do not reflect actual structural or commodity fumigation practices and were excluded from use in this assessment.

Air monitoring methods

1) Bouyoucos and Melcher (1979) reported the original method for collecting air sulfuryl fluoride onto charcoal sorbent tubes, extracting by alkaline hydrolysis and detecting the released fluoride ion by ion chromatography, and published this procedure in 1983 (Bouyoucos *et al.*, 1983). Although NIOSH method 6012 is based upon this procedure (1994), this methodology was not used in the monitoring studies which provided data for this assessment. A modification and validation of the original method was presented by DowElanco in which the detection system was replaced by an ion selective electrode (Murphy and Contardi, 1994). Based on concerns regarding the complete hydrolysis of sulfuryl fluoride and release of a detectable fluoride species, this method (HEH2.12-38-26(6)) was reevaluated and a 66% rather than a 91% recovery was reported (Huff and Murphy, 1995). The Huff and Murphy (1995) method was employed in the monitoring studies providing air concentrations in this assessment.

2) Instrumentation sensitivity:
- Fumiscope Model D, manufactured by Key Chemical and Equipment Co., Inc, Clearwater, FL, can be used to measure sulfuryl fluoride air concentrations up to 1,000 oz/1,000 ft^3, where 1 oz/1,000 ft^3 is approximately equal to 240 ppm or 1 g/m^3.
- MIRAN SapphIRe XL, distributed by Thermo Environmental Instruments, Franklin, Massachusetts, is a portable device appropriate for detection of low sulfuryl fluoride levels up to 30 ppm, with a detection limit of 0.1 ppm (Cohn, 2002). (http://www.thermo.com/eThermo/CDA/Products/Product_Detail/1,1075,15491-156-X-1-13477,00.html#MIRANXL)
- GF1900 Sulfuryl Fluoride (Vikane) Monitor, distributed by Interscan Corporation, Chatsworth, California, is a portable device appropriate for detection of low sulfuryl fluoride levels up to 50 ppm, with an accuracy of ±1 ppm. (http://www.vikanemonitor.com/vmonitor.html)
- A study submitted by the registrant in 1992 reports MIRAN and Interscan readings as low as 0.5 ppm (Bean and Sprint, 1992).
- A study submitted by the registrant in 1995 reports MIRAN sensitivity of 0.3 ppm (Shurdut, 1995).

APPENDIX IV

ILLNESS AND INJURY REPORTS

DPR's Pesticide Illness Surveillance Program (PISP) maintains a database of pesticide-related illnesses and injuries that are reported within California. Medical reports are received from physicians and Workers' Compensation records. These data are used primarily to determine trends in illnesses and injuries produced by a particular pesticide or activity. In structural fumigations, chloropicrin is used as a warning agent with sulfuryl fluoride. For the purpose of evaluating the effects of sulfuryl fluoride, illnesses attributed to the warning agent alone will not be included in this report. See Tables 3, A-4, and A-5 for reported sulfuryl fluoride illnesses/injuries.

Between the years 2000 and 2004, 19 episodes (or exposure incidents) gave rise to 26 case reports in which health effects were evaluated as at least possibly related to sulfuryl fluoride exposure. Three of the 26 affected people were admitted to hospitals, and four lost work time. Eighteen of the 19 episodes resulted in only one or two people affected; the other involved five people (Kings County, 2000) (Mehler, 2006). There was one fatality reported in the five years listed that occurred when an alcoholic man entered his fumigated house though his bedroom window. The structural pest control operator found him dead the next day. The fumigation crew had seen him walking around the home as they tarped it. They suspected he was intoxicated. The coroner noted pulmonary edema, pulmonary congestion and alveolar hemorrhage upon examination.

Most of the illnesses/injuries reported between 2000 and 2004 were non-occupational exposures (16 cases, 62%) and occurred in residential structures, such as apartments and single-family homes (19 cases, 73%). In over half of the total number of reported cases, residents developed symptoms even after the structural pest control operators (SPCO) cleared the structures for reentry. In six cases, residents noticed an odor upon entering their residences. The most common symptoms they reported included burning eyes, eye and throat irritation, nausea and difficulty breathing. In a case involving early reentry, chest pain was also reported.

Table A-4 shows the breakdown of illness/injury types according to types of reported sulfuryl fluoride exposures. The table shows that most of the illnesses occurred as result of an exposure to drift and residue (tied with 10 cases each, 38%). Table A-4 also shows that most of the illnesses involved systemic symptoms (20 cases, 77%), such as nausea, dizziness, and headache. This was followed by respiratory symptoms, which were reported 62% of the time or in 16 cases. Respiratory symptoms reported include difficulty breathing, chest pain, chest tightness, and coughing.

Table A-4. Type of illnesses associated with various types of exposure to sulfuryl fluoride in California from -2004. [a]

Type of Illness/Injury [c,d]	Type of Exposure [b,c]					
	Direct Spray/Squirt	Spill/Other Direct	Drift	Residue	Unknown	Total
Systemic						
• Systemic w/ respiratory, skin and eye				1		1
• Systemic w/ respiratory and eye			1	2		3
• Systemic w/ respiratory			5	2		7
• Systemic w/ eye				2		2
• Systemic only		1	2	1	3	7
Respiratory						
• Respiratory w/ eye		1	1			2
• Respiratory only			1	2		3
Skin						
• Skin only	1					1
Total	1	2	10	10	3	26

[a] [a] Department of Pesticide Regulation (Mehler, 2006).

[b] Types of Exposure

Direct Spill/Other: Includes contact made during an application or mixing/loading operation where the material is not propelled by the equipment or leaks, spills, etc. not related to an application.

Spill/Other direct: Includes contact made during an application or mixing/loading operation where the material is not propelled by the equipment or leaks, spills, etc., not related to an application.

Drift: Includes spray, mist, vapors or odor carried from the target site while an application or mix/load activity is taking place.

Residue: The part of a pesticide that remains in the environment for a period of time following the completion of an application. This includes an odor.

Unknown: Route of exposure is not known.

[c] Defined according to the Pesticide Illness Surveillance Program (PISP) Database User Documentation/Dictionary - Worker Health & Safety Branch, California Department of Pesticide Regulation, May 29, 2001.

[d] Types of Illness/Injury

Systemic: Any health effects not limited to the skin, eye and/or respiratory systems.

Respiratory: Health effects involving any part of the respiratory tree.

Eye: Health effects involving the eyes. This excludes outward physical signs (miosis and lacrimation) related to effects on internal bodily systems.

Skin: Health effects involving the skin.

Table A-5 gives a brief description of all the group episodes (2 or more people) that occurred between the years of 2000 through 2004 listed by year and county of occurrence. In this five-year period, there were 4 group episodes. In one group episode, five people were exposed when high winds caused the tarp on the roof of a fumigated structure to come loose. Employees working near and around the fumigated building reported symptoms as a result of the escaping fumes. Of the four group episodes, there was only 1 incident reportedly involving early reentry (denoted as footnote [b] in Table A-5). A resident reportedly heard noises coming from inside the tarp of their neighbor's fumigated house. Two men had allegedly climbed underneath the tarp when they got cold. The investigator was unable to interview the two men, so this could not be confirmed.

Numerous cases show that even when the aeration period had expired and the buildings were cleared for reentry, symptoms and odors were still reported by the residents. Unfortunately, there is no information on the actual level of sulfuryl fluoride or chloropicrin and there is no means to verify whether that the fumigation and aeration procedures were properly executed at the time of any of the reported incidents. Thus, it is not possible to determine whether a change in the current instructions for aeration or sulfuryl fluoride reentry/clearance levels would have prevented any of the reported illnesses allegedly following proper protocol.

Table A-5. Summary of sulfuryl fluoride group episode scenarios according to county of incident and year of occurrence for the years of 1997-2001. [a]

Year	County	Episode Description	Reported Symptoms
1999	Monterey[b]	Two homeowners entered their recently fumigated home and developed symptoms. The SPCO[c] failed to aerate the house for the legally required number of hours.	Nausea, headache, irritated eyes, nose and throat.
1999	Monterey	Three residents entered their apartment units after they had been cleared for reentry and developed symptoms. Although the building had been properly aerated, some of the residents reported smelling an odor.	Nausea, dizziness, burning eyes, throat irritation.
2000	Kings[b]	Eight correctional officers smelled an odor and developed symptoms 2 days following the fumigation of a prison cafeteria building. High winds had caused the tarp on the roof to come loose.	Headache, nausea, coughing, chest tightness, eye and throat irritation.

[a] Department of Pesticide Regulation (2002 and 2003b).
[b] Exposure occurred prior to the end of the restricted entry period.
[c] SPCO, Structural Pest Control Operator.

APPENDIX V

GLOSSARY OF TERMS

Agricultural use means the use of any pesticide or method or device for the control of plant pests, or the use of any pesticide for the regulation of plant growth or defoliation of plants. It excludes the sale or use of pesticides in properly labeled packages or containers that are intended for any of the following: (a) Home use, (b) Use in structural pest control, (c) Industrial or institutional use, (d) The control of an animal pest under the written prescription of a veterinarian, (e) Local districts or other public agencies that have entered into and operate under a cooperative agreement with the State Department of Health Services pursuant to Section 116180 of the Health and Safety Code, provided that any exemption under this subdivision is subject to the approval of the director as being required to carry out the purposes of this division (CA FOOD AND AGRICULTURAL CODE Sec 11408).

Chamber fumigation refers to the application method in which fumigant is introduced into a gas-tight chamber.

Commodity Fumigation (Nonfood/Nonfeed). includes fumigation of nonfood/nonfeed commodities such as pallets, dunnage, furniture, burlap bags, etc. (beds, mattresses). Application may be performed using tarpaulin, taped or chamber fumigation methods.

Industrial use means use for or in a manufacturing, mining or chemical process; or use in the operation of factories, processing plants, and similar sites (3 CCR 6000).

Institutional use means use within the confines of, or on property necessary for the operation of, buildings such as hospitals, schools, libraries, auditoriums and office complexes (3 CCR 6000).

Landscape Maintenance includes any pest control work performed on landscape plantings around residences, or other buildings, gold courses, parks, cemeteries, etc.

Regulatory Pest Control includes any pest control work performed by public employees or contractors in the control of regulated pests.

Residential use means use of a pesticide directly: (1) On humans or pets, (2) In, on, or around any structure, vehicle, article, surface, or area associated with the household, including but not limited to areas such as non-agricultural outbuildings, non-commercial greenhouses, pleasure boats and recreational vehicles, or (3) In any preschool or day care facility (40 CFR 152.3).

Right-of-Way Pest Control includes any pest control work performed along roadsides, power lines, median strips, ditch bands and similar sites.

Structural Pest Control includes any pest control work performed within or on buildings and other structures.

Structural use means a use requiring a license under Chapter 14 (commencing with Section 8500), Division 3 of the Business and Professions Code. 3 CCR 6000.

Taped fumigation refers to the application method in which the fumigant is introduced into a structure which has been enclosed using plastic, paper, or tape to seal around doors, windows, vents, and other openings.

Tarpaulin fumigation refers to the application method in which fumigant is introduced into a structure which has been enclosed using a tarp of highly resistant material such as vinyl coated nylon, or polyethylene sheeting of at least 4 ml thickness. All seams are sealed to create a gas-tight enclosure. Low edges of the tarp are weighted down, for example with soil or sand. For a fumigant of low water solubility such as sulfuryl fluoride, ground soil immediately surrounding the structure is moistened with water to act as a barrier to the gas.

Vertebrate Pest Control includes any pest vertebrate pest control work performed by public agencies or work under the supervision of the State or county agricultural commissioner.

APPENDIX VI

EXPLANATION OF MODELS USED IN RESIDENT/OCCUPANT EXPOSURE

Model 3

The "full model" is Model 3 specified as follows:

$E(y)$ = expected value of the ln(conc(ppm))

T = time in hours post-clearance

H_i = house$_i$ dummy variable, where I = 1,…,6

In that case, the regression model is shown below:

$$E(y) = \grave{o}_0 + \grave{o}_1T + \grave{o}_2H_1 + \grave{o}_3H_2 + \grave{o}_4H_3 + \grave{o}_5H_4 + \grave{o}_6H_5 + \grave{o}_7H_6 + \grave{o}_8TH_1 + \grave{o}_9TH_2 + \grave{o}_{10}TH_3 + \grave{o}_{11}TH_4 + \grave{o}_{12}TH_5 + \grave{o}_{13}TH_6$$

There are 14 terms and regression parameters in this model, the intercept, the regression parameter associated with time, six regression parameters associated with the six dummy variables for house, and six regression parameters associated with the interaction between time and house.

The dummy variables are as follows:

H_i = 1 if an observation is from the i^{th} house; $i = 1,\ldots,6$
0 otherwise

This specification of the dummy variables defines house 7 as the base case, i.e. when all dummy variables $i = 1,\ldots,6$ are zero, then house 7 is specified.

Therefore:

$E(y) = \grave{o}_0 + \grave{o}_1T$ = expected value for house 7

$E(y) = (\grave{o}_0 + \grave{o}_2) + (\grave{o}_1+\grave{o}_8)T$ = expected value for house 1

$E(y) = (\grave{o}_0 + \grave{o}_3) + (\grave{o}_1+\grave{o}_9)T$ = expected value for house 2

$E(y) = (\grave{o}_0 + \grave{o}_4) + (\grave{o}_1+\grave{o}_{10})T$ = expected value for house 3

$E(y) = (ò_0 + ò_5) + (ò_1+ò_{11})T$ = expected value for house 4

$E(y) = (ò_0 + ò_6) + (ò_1+ò_{12})T$ = expected value for house 5

$E(y) = (ò_0 + ò_7) + (ò_1+ò_{13})T$ = expected value for house 6

The test for interaction should really be done first, because, if there is a significant interaction it must be included in the model. The Model 3 test for an interaction (comparison of the R^2 values between Models 3 and 2) determines whether the regression parameters, $ò_8$ through $ò_{13}$ are significantly different from zero.

Model 2

Model 2 drops the interaction terms from the model, that's all the terms, $ò_iTH_i$; i = 1,…,6

Comparison of the R^2 values suffices to determine that Model 2 is an adequate model because there is no apparent interaction between time and house. This means that if there are multiple regression lines, they are parallel (all have the same slope). Since there was only a small decrease in the R^2 value from Model 3 to Model 2 and there was an increase in the adjusted R^2 values from Model 3 to Model 2 we can assume there is no significant interaction. We could also perform an "extra sum of squares test" but the lack of interaction is obvious so it probably is not necessary unless we want to be totally complete.

Model 2 is shown below:

$E(y) = ò_0 + ò_1T + ò_2H_1 + ò_3H_2 + ò_4H_3 + ò_5H_4 + ò_6H_5 + ò_7H_6$

In this case the expected values are as follows:

$E(y) = ò_0 + ò_1T$ = expected value for house 7

$E(y) = (ò_0 + ò_2) + ò_1T$ = expected value for house 1

$E(y) = (ò_0 + ò_3) + ò_1T$ = expected value for house 2

$E(y) = (ò_0 + ò_4) + ò_1T$ = expected value for house 3

$E(y) = (ò_0 + ò_5) + ò_1T$ = expected value for house 4

$E(y) = (ò_0 + ò_6) + ò_1T$ = expected value for house 5

$E(y) = (ò_0 + ò_7) + ò_1T$ = expected value for house 6

The parallel lines, with only a difference in elevation, are obvious because the rate of change with time, T, is the same for all seven houses. The test for whether there are significant differences in elevation (the intercept terms) between the equations for the houses is the test for the "house main effect." This test determines whether any, or all, of the regression parameters, $ò_2$ through $ò_7$ are different from zero. This comparison was made by looking at the difference between the R^2 values between Model 2 and Model 1.

Model 1

Model 1 drops the $ò_iH_i$; $i = 1,\ldots6$, terms in Model 2. Model 1 does not include any dummy variables that identify houses. Model 1 is shown below:

$$E(y) = ò_0 + ò_1T$$

Model 1 treats all observations as if they are random samples with no systematic differences. Unfortunately, we know from the very large decrease in R^2 values between Model 2 and Model 1 that there is a very large house main effect. This means that at least some of the regression parameters, $ò_2$ through $ò_7$, are significantly different from zero. Because the house main effect is not include in Model 1, the variance estimate associated with Model 1 includes the large variance due to the systematic difference between houses.