ESTIMATION OF EXPOSURE OF PERSONS IN CALIFORNIA TO PESTICIDE PRODUCTS THAT CONTAIN CARBOFURAN

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ABSTRACT

Carbofuran is a carbamate insecticide/miticide that has been registered in California since 1974, exclusively for agricultural uses. One formulation is currently registered in California, a liquid flowable formulation containing 44% active ingredient that is a Restricted Use Pesticide. Carbofuran may be applied to foliage by ground or air methods, to soil during planting, by chemigation, as a dip/slurry, or by drenching. This exposure assessment was performed in response to adverse reproductive, chronic, and genotoxic effects observed in animal model studies. Metabolic and toxicity studies using laboratory animals suggest that the principle metabolite, 3-hydroxy carbofuran, has a similar toxicity to the parent compound.

Significant exposure scenarios were identified based on uses listed on product labels. A total of nine handler and three reentry scenarios were identified. As acceptable exposure data were lacking, handler exposures were estimated using surrogate data from the Pesticide Handler Exposure Database and two models from the U.S. Environmental Protection Agency; reentry exposures were estimated using dislodgeable foliar residue data for carbofuran from several studies and transfer coefficients from surrogate chemicals. Acute Absorbed Daily Dosage (Acute ADD) estimates for handlers ranged from 0.002 mg/kg/day to 6.40 mg/kg/day. Seasonal, Annual and Lifetime ADD estimates for handlers ranged 0.0006 – 2.14 mg/kg/day; 0.0001 – 0.357 mg/kg/day; and 0.0001 – 0.190 mg/kg/day, respectively. Acute ADD estimates for fieldworkers in potentially significant exposure scenarios were 0.007 mg/kg/day for cotton scouts, 0.099 mg/kg/day for alfalfa scouts and 0.016 mg/kg/day for potato scouts. Seasonal, Annual and Lifetime ADD estimates for cotton scouts were 0.0009, 0.0001 and 0.00008 mg/kg/day. Seasonal, Annual and Lifetime ADD estimates for alfalfa scouts were 0.070, 0.012, and 0.006 mg/kg/day. Seasonal, Annual and Lifetime ADD estimates for potato scouts were 0.010, 0.002, and 0.001 mg/kg/day.
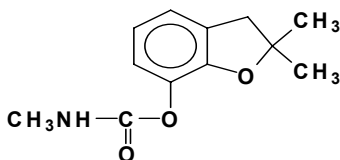
Ambient air exposures and bystander exposures during applications were estimated as well. Acute ADD for ambient air exposures in Imperial County ranged 0.000004 – 0.000070 mg/kg/day for infants and 0.000002 – 0.000034 mg/kg/day for adults. Acute ADD for ambient air exposures in Sacramento County ranged 0.0000014 – 0.0000016 mg/kg/day for infants and 0.0000007 – 0.0000008 mg/kg/day for adults. Seasonal ADD ranged 0.000004 – 0.000020 mg/kg/day for Imperial County and 0.0000002 – 0.0000005 mg/kg/day for Sacramento County. Annual ADD ranged 0.000001 – 0.000003 mg/kg/day for Imperial County and 0.00000007 – 0.0000002 mg/kg/day for Sacramento County.

Bystander exposure estimates were based on air monitoring done 20 meters from the edge of an Imperial County alfalfa field. Acute ADD for bystanders was 0.000454 mg/kg/day for infants and 0.000216 mg/kg/day for adults. These estimates were based on a 24-hour time-weighted average concentration and an assumption of typical activity levels. As available information suggests that exposures of less than 24 hours can result in toxicity, 1-hour absorbed dose estimates were calculated as well, based on the highest measured concentration during a one-hour measuring period and an assumption of heavy activity. These 1-hour absorbed dose estimates were 0.000550 mg/kg/hr for infants and 0.000099 mg/kg/hr for adults. Seasonal and annual exposures for bystanders were not estimated separately, because airborne concentrations are anticipated to reach ambient levels within a few days after each application.

INTRODUCTION

Carbofuran (2,2-dimethyl-2,3-dihydro-7-benzofuranyl-N-methylcarbamate or 2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate) is sold under the trade name Furadan® (FMC Corporation). As a carbamate, it is a cholinesterase inhibitor (Gupta, 1994). It is a broad-spectrum insecticide, acaricide, and nematicide, and has been shown to be absorbed and translocated by certain plants (Arunachalam and Lakshmanan, 1982; Buyanovsky *et al*., 1995).

Technical carbofuran is a white crystalline solid whose empirical formula is $C_{12}H_{15}NO_3$. It has the following chemical structure:

The molecular weight of carbofuran is 221.26. Selected physicochemical properties include water solubility of 351 ppm @ 25° (Evert, 2002); melting point of 153-154 °C (Alvarez, 1987); and vapor pressure of 6×10^{-7} mm Hg @ 25°C (Alvarez, 1989).

The octanol/water partition coefficients (K_{ow}) for carbofuran were measured as 17 and 26 in 1 and 10 µg/L solutions, respectively (Brandau, 1975). The log K_{ow} for carbofuran would be 1.23 – 1.42. The K_{ow} differed only slightly between solutions with different carbofuran concentrations, and was not considered to be affected by concentration (Brandau, 1975). The vapor pressure and water solubility reported above were used to calculate a Henry's Law constant of 5×10^{-10} atm-m^3/mole (Ferraro, 1989). Airborne carbofuran is reported to be photooxidized by reacting with hydroxyl radicals; the half-life of this reaction is estimated at 4.6 hours (Evert, 2002).

Carbofuran is stable under neutral or acid conditions and readily hydrolyses in basic solution (McCarthy, 1975). The rate of base-catalyzed hydrolysis increases with increasing pH (McCarthy, 1975; Gupta, 1994; Mohapatra and Awasthi, 1997; Evert, 2002). The half-life of carbofuran varies from 1 – 2 days in rice paddy water, and 2 – 5 weeks in soils during the growing season, to 3 – 5 months during the winter (McCarthy, 1975). It does not bioaccumulate (McCarthy, 1975; Evert, 2002), and its degradation can be both chemical and microbial (Kross *et al.*, 1992; Mohapatra and Awasthi, 1997). In water and soils, it decomposes to carbon dioxide, methylamine, and carbofuran phenol (McCarthy, 1975).

Carbofuran has been assigned to Toxicity Category I by the U.S. Environmental Protection Agency (U.S. EPA), based on responses to exposure via the oral, inhalation and dermal routes (U.S. EPA, 1984). As a carbamate, it is a reversible cholinesterase inhibitor, with recovery of inhibited enzyme occurring in as little as a few hours (Gupta, 1994). All carbofuran products are classified by U.S. EPA as restricted-use pesticides due to concern about inhalation toxicity (Title 40 Code of Federal Regulations (CFR), Section 152.175), and are listed as restricted-use pesticides under California regulations as well (Title 3 Code of California Regulations (3 CCR), Section 6400).

The Department of Pesticide Regulation (DPR) is charged with protecting individuals and the environment from potential adverse effects that may result from the use of pesticides in the State (California Food and Agriculture Code (CFAC), Sections 11501, 12824, 12825, 12826, 13121-13135, 14102, and 14103). As part of DPR's effort to meet this mandate, pesticide active ingredients (AIs) are prioritized for assessment of exposure and risk potential (DPR, 2004). Following this prioritization process, AIs are evaluated in accordance with California regulation (3 CCR 6158). Carbofuran is being evaluated based on adverse reproductive, chronic, and genotoxic effects observed in laboratory studies. This Exposure Assessment Document (EAD) is the first prepared by DPR for carbofuran.

U.S. EPA STATUS

U.S. EPA issued a reregistration guidance document for carbofuran (U.S. EPA, 1984), which outlined their regulatory position on the use of carbofuran products. Subsequently, based on acute adverse effects on avian species, six positional documents were issued in the Federal Register (FR) restricting carbofuran uses, application methods, and formulations (50 FR 41938, 16 October 1985; 54 FR 3744, 25 January 1989; 55 FR 42266, 18 October 1990; 56 FR 33286, 19 July 1991; 56 FR 64621, 11 December 1991; 60 FR 11090, 1 March 1995). Use on rice, which was one of the uses voluntarily cancelled, was conditionally extended through 2000 (60 FR 11090, 1 March 1995). Carbofuran use on rice was discontinued after the 2000 growing season (66 FR 39709, 1 August 2001).

Because of the acute avian risk posed by the use of flowable carbofuran products (Furadan® 4F Insecticide-Nematicide, EPA Reg. No. 279-2876), the U.S. EPA cancelled uses on grapes and strawberries in 1997 (62 FR 6775, 13 February 1997). As of October 2001, three Special Local Need (SLN, Section 24c of the Federal Insecticide, Fungicide, and Rodenticide Act, or FIFRA) uses were registered in California to control specific pests on grapes; applications are allowed via drip irrigation only (CA SLN No. 940005, CA SLN No. 980011, and CA SLN No. 980012). Two other SLN uses were registered as well, to control specific pests on ornamental plants (CA SLN No. 830058) and artichokes (CA SLN No. 860037). Emergency exemptions (FIFRA Section 18) issued in 1999 – 2003 allowed foliar uses on cotton to control cotton aphids in California. No emergency exemption was issued in 2004, nor has one been issued or requested as of July 2005. However, foliar applications to cotton are considered in this EAD, in case emergency exemptions are issued in the future.

Dietary risks are being evaluated by the U.S. EPA as required under the Food Quality Protection Act. One food tolerance, for carbofuran residues on rice, has already been revoked and will not be evaluated (66 FR 39709, 1 August 2001). This tolerance was revoked because use of granular carbofuran on rice is no longer allowed, in response to concern about avian toxicity. As part of its pesticide Reregistration Eligibility Decision process required by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), U.S. EPA recently released human occupational exposure and preliminary risk assessments for carbofuran (Drew *et al.*, 2005; Weiss, 2005).

FORMULATIONS AND USES

Just one carbofuran formulation is registered in California, a 44% AI flowable liquid concentrate, Furadan® 4F Insecticide-Nematicide (EPA Reg. No. 279-2876). A 5% AI granular formulation, Furadan® 5G Insecticide-Nematicide (EPA Reg. No. 279-50634), was registered until 2001 as a SLN registration (CA SLN No. 970005) for use on rice. The registration for a granular formulation was withdrawn by U.S. EPA and was not considered in this exposure assessment. Carbofuran may be applied as a foliar spray by aerial or ground equipment, as a soil application, by irrigation (SLN No. CA-980012 for winegrapes), as a dip, or by drenching (SLN No. CA-830058 for container grown ornamental plants in nurseries or greenhouses). Maximum application rates for Furadan® 4F range from 0.5 pints/acre (0.25 lbs AI/acre, or 0.28 kg AI/hectare (ha)) applied as a foliar application (e.g., on cotton) to 2.5 gallons/acre (10 lbs AI/acre, or 11 kg AI/ha) applied as a soil drench (e.g., on field-grown ornamentals).

Table 1 summarizes carbofuran use in California in the years 1999 through 2003, the most recent five years for which data are available (DPR, 2000, 2001, 2002, 2003, 2005a). The three crops receiving most of the carbofuran applications were alfalfa (forage, fodder/hay), grapes (table and wine), and cotton. Annual use on these three crops in the years 1999 through 2003 accounted for greater than 70% of all carbofuran uses (mean: 90%, range: 74 – 98%). Use on rice has not been allowed since 2000. Although dip/slurry use on pine seedlings is allowed in California, a review of the 1991 – 2003 PUR shows no reported uses on pine seedlings (DPR, 2005b).

Table 1. Carbofuran Use in California Between 1999 and 2003 [a]

Crop	Pounds applied (% total in state)				
	1999	2000	2001	2002	2003
Alfalfa [b]	64,442 (46.6)	65,333 (49.3)	39,316 (41.0)	41,920 (53.3)	37,182 (45.5)
Grapes	26,225 (19.0)	21,709 (16.8)	15,394 (16.1)	14,876 (18.2)	7,921 (9.7)
Cotton [c]	12,848 (9.3)	26,359 (19.9)	38,829 (40.5)	21,938 (26.9)	1,832 (2.2)
Nursery	1,629 (1.2)	1,044 (0.8)	1,524 (1.6)	1,528 (1.9)	1,072 (1.3)
Artichokes [b]	2,289 (1.7)	1,067 (0.8)	715 (0.7)	527 (0.6)	882 (1.1)
Bermudagrass	1,006 (0.7)	0 (0.0)	15 (0.0)	75 (0.1)	0 (0.0)
Rice	29,014 (21.0)	14,547 (11.3)	0 (0.0)	3 (0.0)	0 (0.0)
Other crops [d]	759 (0.5)	314 (0.2)	70 (0.1)	783 (1.0)	385 (0.5)
Total	138,212	128,618	95,863	81,650	49,275

[a] DPR (2000, 2001, 2002, 2003, 2005a). Crops arranged in descending order by use in 2003.
[b] Foliar applications of carbofuran are allowed on this crop.
[c] The product label allows applications at planting only. Section 18 emergency exemptions issued each year between 1999 and 2003 allowed foliar use to control cotton aphids (exemption has not been issued since 2003).
[d] Includes the following crops on which foliar applications of carbofuran are allowed: potatoes, barley, oats, wheat, soybeans and sugarcane. Foliar applications are allowed on sweet corn that is mechanically harvested, and on field corn that has not received post-plant soil applications.

Total carbofuran use declined between 1999 and 2003, as did use on alfalfa, grapes and cotton (Table 1). Annual use on cotton was greater in 2000 – 2002 than in 1999 or 2003. Insecticide use in general increased in cotton between 2002 and 2003, but most of the increase was of newer, "low risk" insecticides rather than insecticides such as carbofuran (DPR, 2005a).

Worker exposure to carbofuran may be anticipated to occur during handling (mixing, loading, flagging, and application), and during reentry activities, such as scouting, thinning and harvesting of crops that have received foliar applications of carbofuran (these crops have been indicated in Table 1). Additionally, carbofuran was detected in monitoring of ambient air in some urban and rural areas and in air near application sites, suggesting that public exposure to airborne carbofuran might occur.

REPORTED ILLNESSES

Reports of illness and injury associated with definite, probable, or possible exposure to pesticide products are recorded in a database maintained by the Pesticide Illness Surveillance Program (PISP) at DPR. The PISP database contains information about the nature of the pesticide exposure and the subsequent illness or injury. "Definite" means that both physical and medical evidence document exposure and consequent health effects, "probable" means that circumstantial evidence supports a relationship to pesticide exposure, and "possible" means that evidence neither supports nor contradicts a relationship (DPR, 2005c).

Between 1992 and 2003, a total of 77 reports of illnesses, injuries, or death associated with exposure to carbofuran, alone or in combination with other pesticides, were received by PISP (Verder-Carlos, 2005). Most of the illnesses were systemic in nature (69 of 77, about 90% of the total cases), with complaints of nausea, vomiting, abdominal cramps, headache, and dizziness (Verder-Carlos, 2005). The other eight incidents consisted of injuries or irritation to eyes, skin or throat. There were two reported cases of hospitalization, one in 1994 and one in 1998, and 37 cases involving disability that ranged from one to twenty-eight days. A single reported death in 1999 followed ingestion of carbofuran; no other deaths have been associated with carbofuran exposures in California.

Of the 77 total illness reports received by PISP, 56 came from occupational exposures, in which the subjects were working with or near carbofuran (or multiple pesticides that included carbofuran), or were working in treated areas. Of the individuals reporting illness following occupational exposures, three were mixer/loaders and five were applicators. Thirty-six workers reported illness after entering a field treated with carbofuran. Most of the other exposures occurred when carbofuran drifted from a nearby application.

Two incidents resulted in multiple illness reports to PISP. Following a drift incident in 1993, 19 residents from a single neighborhood reported symptoms including headache, dizziness, nausea, and irritated throat and eyes (Verder-Carlos, 2005). In 1998, 34 field workers began weeding a treated cotton field two hours after an application of carbofuran, mepiquat chloride, and abamectin (Das *et al*., 1999; Edmiston *et al*., 1999). The exposure duration was approximately 3.5 hours; shortly afterward, the workers developed symptoms including headache, nausea,

vomiting, diarrhea, eye irritation, respiratory problems, salivation, and muscle weakness. Carbofuran and 3-hydroxycarbofuran residues were detected in foliage samples collected from the field, as well as in clothing and urine samples taken from the affected workers. Additionally, red cell cholinesterase activity was below the normal range for all ten workers from whom blood samples were drawn (Edmiston *et al*., 1999).

LABEL PRECAUTIONS AND CALIFORNIA REQUIREMENTS

Furadan® 4F (44% AI) has been assigned Toxicity Category I due to oral and inhalation toxicity. The signal word on the label is DANGER. Due to its acute oral and inhalation toxicity, carbofuran is classified as a Restricted Use Pesticide according to U.S. EPA (40 CFR 152.175) and under California regulation (3 CCR 6400). As a Toxicity Category I pesticide, carbofuran has additional requirements under the California Worker Safety Regulations. A closed system is required during mixing and loading, unless one gallon or less is handled per day from the original one gallon container (3 CCR 6746). Pilots are required to use a closed system during handling if the pesticide is an organophosphate or a carbamate and is Toxicity Category I (3 CCR 6544).

With regard to protective clothing, the label states that applicators and other handlers must wear long-sleeved shirt, long pants, shoes, and socks. Required personal protective equipment (PPE) for handlers includes chemical resistant gloves for all handling tasks, and protective eyewear when mixing or loading, cleaning out or repairing contaminated equipment. In enclosed areas, a Mine Safety and Health Administration/National Institute of Occupational Safety and Health (MSHA/NIOSH) approved vapor barrier pesticide mask is required. For outdoor use, a MSHA/NIOSH approved pesticide dust/mist filtering respirator is required. Ground applicators and flaggers (unless flaggers work in enclosed cabs) are required by California regulation to wear protective eyewear (3 CCR 6738).

As carbofuran products are legally required in California to be mixed and loaded in closed systems, alternate PPE may be substituted for PPE listed on product labels. Under the federal Worker Protection Standard (40 CFR 170.240), "Persons using a closed system to mix or load pesticides with a signal word of DANGER or WARNING may substitute a long-sleeved shirt, long pants, shoes, socks, chemical-resistant apron, and any protective gloves specified on the labeling for handlers for the labeling-specified personal protective equipment." Additionally, under the Worker Protection Standard, "Persons using a closed system that operates under pressure shall wear protective eyewear."

The corresponding California regulations have more restrictive PPE requirements (3 CCR 6738): "Persons using a closed system to handle pesticide products with the signal word 'DANGER' or 'WARNING' may substitute coveralls, chemical resistant gloves, and a chemical resistant apron for personal protective equipment required by pesticide product labeling." Also, "Persons using a closed system that operates under positive pressure shall wear protective eyewear in addition to the personal protective equipment listed...Persons using any closed system shall have all personal protective equipment required by pesticide product labeling immediately available for use in an emergency."

Requirements for PPE that are unique to California were incorporated into worker exposure estimates in the following manner: closed systems were assumed for M/L, and PPE required on the label were assumed because both the Worker Protection Standard and the corresponding California regulation (3 CCR 6738) state that PPE *may* be substituted. That is, substitution of PPE during use of a closed system is optional, and the PPE stated on the label is less protective than the substitute PPE listed in the federal Worker Protection Standard (40 CFR 170.240), and in California regulations (3 CCR 6738), both of which require use of a chemical apron. Adjustments of dermal exposure estimates for use of substitute PPE would result in lower estimates than estimates that assume use of label-required protective clothing and PPE, which includes a respirator. As a result, the most health-protective, realistic exposure estimates use PPE listed on product labels (see below, in the Exposure Assessment section).

According to requirements listed on the label, the Restricted Entry Interval (REI) is 48 hours except for foliar application to cotton, corn, sunflowers, and sorghum, for which the REI is fourteen days. For these crops, early reentry on day 2 or later may be permitted, without time limit, for non-handler work tasks that may involve contact with treated surfaces/sites provided the following PPE is worn: coveralls, chemical-resistant gloves, shoes, and socks.

PHARMACOKINETICS

Dermal and Inhalation Absorption

For carbofuran, no *in vivo* human dermal absorption studies are available, although reports of two *in vivo* and two *in vitro* dermal absorption studies have been published in the scientific literature. The first *in vivo* study examined dermal penetration rates of several pesticides in mice (Shah *et al*., 1981). The second *in vivo* study compared dermal penetration of carbofuran in young and adult female rats (Shah *et al*., 1987a; 1987b). The first *in vitro* study compared dermal penetration of several pesticides, including carbofuran, through human foreskin pieces mounted in a static diffusion chamber (Shehata-Karam *et al*., 1988). The second *in vitro* study compared dermal penetration of three pesticides, including carbofuran, through rat abdominal skin mounted in a static diffusion chamber (Liu and Kim, 2003).
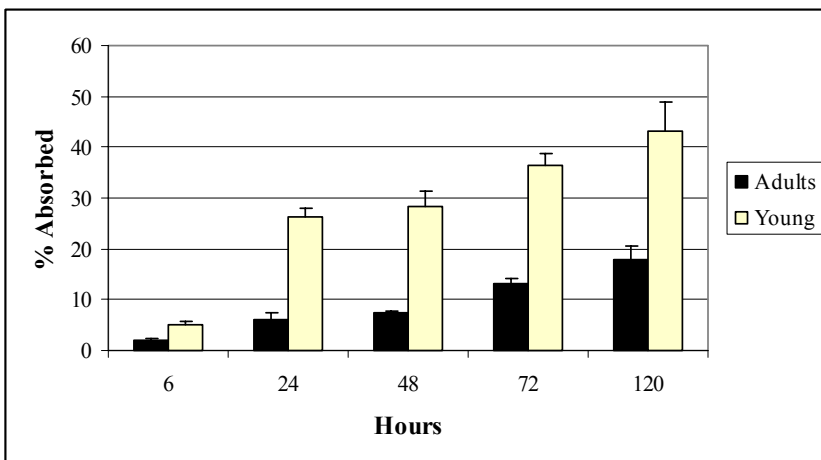
In Vivo Studies

In the first study (Shah *et al*., 1981), female mice aged seven to eight weeks were used. Radiolabeled pesticides dissolved in acetone were applied at a rate of 1 mg/kg to shaved skin areas of 1 cm^2. The carbofuran used in this study was ring-labeled (specific activity 2.85 mCi/mmol). Mice were kept in metabolism cages with CO_2-trapping devices after dosing. The dose site was unprotected, though mice were not observed to groom during the study. Groups of three mice were euthanized following intervals of 1, 5, 15, 60 and 480 min. Following euthanasia, 3- to 4-cm^2 patches of skin were excised (not washed first) to determine the amount of unabsorbed radioactivity. The percentage of radioactivity recovered from carcass, blood and urine was compared to that in skin from the dose site (total recovered radioactivity was > 90% for all compounds). Shah *et al*. (1981) concluded their data showed that carbofuran penetrated mouse skin rapidly. At 5 min post-dose, 32.6% of recovered radioactivity had been absorbed,

and at 15 min post-dose, 71.7% of recovered radioactivity had been absorbed. Shah *et al.* (1981) estimated the half-life for dermal penetration through mouse skin of carbofuran in an acetone vehicle to be 7.7 min; at 8 hours, 94.7% had penetrated (geometric mean of three animals).

The second study was reported in Shah *et al.* (1987a; 1987b). Briefly, young (33-day-old) and mature (82-day-old) female Fisher 344 rats were used, and dermal penetration was studied via both *in vivo* and *in vitro* methods. In the *in vivo* study, ring-labeled ^{14}C-carbofuran (specific activity 39.4 mCi/mmol), diluted with 100 µl and 200 µl of acetone for the young and adults respectively, was assayed at doses of 28, 285, 535, and 2680 nmol/cm^2 (equivalent to 6.2, 63, 118, and 593 µg/cm^2), following an exposure duration of 72 hours; also, the penetration of one dose (285 nmol/cm^2) was reported following multiple exposure durations (6, 24, 48, 72, and 120 hours). Treated areas were 2.8 cm^2 for young rats and 5.6 cm^2 for the adults. The dose site was protected by perforated plastic blister glued to the site. Following euthanasia, treated skin was excised (not washed first) to determine the amount of unabsorbed radioactivity. Dermal absorption was calculated by subtracting the radioactivity recovered from the application site from total radioactivity recovered from all tissues (i.e., bound skin residues were considered unabsorbed). Two major results reported in this study were that dermal penetration in young animals generally exceeded that in adults (see Figure 1), and that dermal penetration was inversely proportional to the applied dose, over the range of doses tested (see Figure 2). At 120 hours, the mean *in vivo* dermal penetration of a mid-level dose (285 nmol/cm^2) was 43% in young rats and 18% in adults (Figure 1). At 72 hours, mean dermal penetration in mature rats ranged from 6% of the high dose to 83% of the low dose, though the 83% was anomalously high compared to other results (Figure 2; also compare Figure 1). Dermal penetration in young rats at 72 hours ranged from 4% of the high dose to 36% of the next-to-lowest dose tested.

Figure 1. Dermal Absorption of Carbofuran at Multiple Exposure Durations [a]

[a] Dermal absorption of carbofuran (285 nmol/cm^2) in acetone solution applied to skin of clipped mid-dorsal back of female adult (age 82 days) and female young (age 33 days) rats. Data from Table 1 of Shah *et al.* (1987b).

Both *in vivo* studies are anticipated to overestimate dermal absorption in humans. Both studies used acetone as a vehicle. Acetone has been shown to increase dermal absorption of several compounds, including pesticides (Moody *et al.*, 1992; Baynes *et al.*, 1997; Baynes and Riviere, 1998; Tsai *et al.*, 2001). Organic solvents can damage the skin barrier properties, artificially

increasing dermal penetration (Scheuplein and Ross, 1970; Fartasch, 1997; Williams and Barry, 2004). For this reason, U.S. EPA (1998a) recommends that the vehicle used in dermal penetration studies should be the same as that "under which field exposure occurs," and states that organic solvents "must not be used."

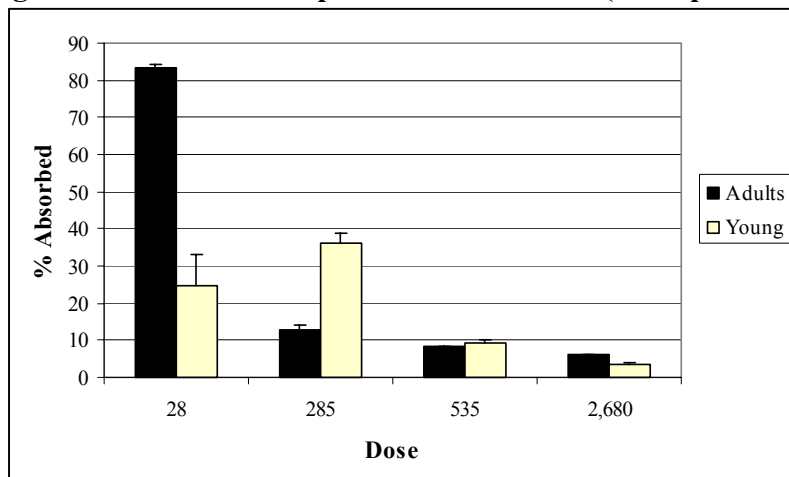**Figure 2. Dermal Absorption of Carbofuran (Multiple Doses) at 72 Hours [a]**

[a] Dermal absorption of carbofuran in acetone solution applied to skin of clipped mid-dorsal back of female adult (age 82 days) and female young (age 33 days) rats. Doses in nmol/cm^2. Lowest dose was 28 nmol/cm^2 (or 6.2 μg/cm^2) for young rats, but 23 nmol/cm^2 (or 5.1 μg/cm^2) for adults. Data from Table 3 of Shah *et al.* (1987b).

The highest dermal absorption of carbofuran, 94.7%, was reported in mice (Shah *et al.*, 1981). Comparison of the four other pesticides tested at comparably low doses in these two studies in both mice (at a dose of 20 μg/cm^2) and rats (at doses ranging 2 – 37 μg/cm^2) showed that in each case absorption was lower in rats following 72 hours of exposure than in mice following 8 – 48 hours exposure (Shah *et al.*, 1981; Shah *et al.*, 1987a). Furthermore, dermal absorption of all fourteen pesticides tested in mice by Shah *et al.* (1981) exceeded 65% at 8 hours, suggesting that all of these results were higher than would normally be anticipated. For four of the pesticides tested by Shah *et al.* (1981) in mice, Ross *et al.* (2001) reported human dermal absorption of 10% or less. In other studies involving pesticides, mice also showed higher dermal absorption than rats or humans (U.S. EPA, 1992; Baynes *et al.*, 1997). Because of the use of mice, but mainly due to the use of acetone as a vehicle, the study by Shah *et al.* (1981) was considered unacceptable.

The highest mean dermal absorption of carbofuran reported in rats was 83% (Shah *et al.*, 1987b). Figure 1 and Figure 2 show this result to be more than double any other result in the study, and in contrast to the pattern seen with other doses it occurred in adults rather than young rats. Because results were presented on a wet-weight basis, and no organ wet weights were given, these discrepancies could not be investigated, nor were they explained by Shah *et al.* (1987b). With the exception of this one result, all dermal absorption results for all dose levels and exposure intervals were less than 40%. U.S. EPA used this study to estimate a dermal absorption of 6%, based on the 24-hour absorption of 285 nmol/cm^2 doses in adults (Drew *et al.*, 2005).

In addition to the use of acetone as a vehicle, there were other ways in which the study conducted by Shah *et al*. (1987b) did not conform to accepted methods (Thongsinthusak, 1994; U.S. EPA, 1998a). The treated skin was covered with a perforated plastic blister, which is possibly an occlusive cover. The treated skin was not washed off after the exposure period. Doses tested for durations approximating a workday (8 hours) were too high (Thongsinthusak *et al*., 1999). Treated areas measured 2.8 cm^2 for the juveniles and 5.6 cm^2 for the adults, rather than the recommended 10 cm^2. The first two of these factors might be expected to result in overestimation of dermal absorption, and the latter two might result in underestimation. Along with the use of acetone as a vehicle, all of these factors undermine use of these data to reliably predict dermal absorption of carbofuran and this study was considered unacceptable.

In Vitro Studies

In the first study, *in vitro* dermal penetration was studied using foreskin segments from newborn humans (Shehata-Karam *et al*., 1988). Briefly, the tissue was obtained immediately after circumcision, kept moist on ice until used, and then mounted in a modified static diffusion chamber with nutrient media. Tests were run at 37°C. Pesticides were applied at a dose of 38 μg/cm^2, dissolved in 1 μl of acetone. Samples were collected from the media at intervals of 1, 6, 24, and 48 hours. The dermal penetration of carbofuran at 48 hours was 82%, a value which agrees with the 72-hr low-dose *in vivo* absorption result of Shah *et al*. (1987b). As both studies used acetone as a vehicle, the similarity in results is perhaps not surprising.

In the second study, *in vitro* dermal penetration was studied using strips of abdominal skin obtained from male Sprague-Dawley rats that were 5-6 weeks old (Liu and Kim, 2003). Skin membranes (3.14 cm^2) were placed into diffusion chambers with physiological saline media immediately after they were obtained. Technical grade pesticides were applied in varying amounts ranging from 2 mg to 150 mg, dissolved in 100 μL of acetone. Tests were run at 32°C, with continuous shaking at 600 rpm for 48 hours. Samples were collected from the media at intervals of 6, 12, 24, 36, and 48 hours. The limit of detection was 0.1 ppm for all pesticides. The dermal penetration rate was estimated by plotting percent absorbed by time, and fitting a least-squares regression to the steady-state linear portion of the curve. For carbofuran, the steady-state linear equation was 1.05 μg/cm^2 per hour (Liu and Kim, 2003).

Both *in vitro* studies used acetone as a vehicle, and are considered unacceptable. Furthermore, the use of *in vitro* studies to determine dermal absorption is problematic because the extent of compound solubility in receptor solutions may affect results and because relationships between *in vivo* and *in vitro* test results have not been reliably established for many classes of compounds, and have been shown to vary for compounds that have been tested (Franklin *et al*., 1989; Wester and Maibach, 2000; Zendzian and Dellarco, 2003). Therefore, DPR does not, by standard practice, rely on *in vitro* studies to determine dermal absorption.

Dermal Absorption Estimate Used in Exposure Assessment

When no acceptable data are available for dermal absorption, DPR policy is to use a default value of 50% (Donahue, 1996). This default value is based on a review of data from forty pesticides, twenty-six of which were documented in Thongsinthusak *et al*. (1993b).

Inhalation Absorption Estimate Used in Exposure Assessment

No inhalation absorption data are available for carbofuran, although the disposition of inhaled aerosolized carbonyl-^{14}C-carbofuran was investigated in rats by Ferguson *et al.* (1982). Male Sprague-Dawley rats were exposed in nose-only chambers to either 4.1 or 1.5 μM aerosols for 50 and 70 minutes, respectively. Exposed rats were immediately exsanguinated by cardiac puncture after exposure and dissected. Tissues were frozen until analysis. Relative disposition was reported by Ferguson *et al.* (1982), rather than absorption data, although based on the theoretical estimate of inhaled dose the deposition was estimated to be 89% of the 4.1 μM and 77% of the 1.5 μM aerosol. In the absence of absorption data, a default inhalation absorption value of 100% was used for calculations of doses absorbed via inhalation.

Metabolism

In a series of *in vivo* and *in vitro* studies, Dorough (1968), Metcalf *et al.* (1968), Marshall and Dorough (1979), and Ferguson *et al.* (1984) found that the most common major metabolite of carbofuran is 3-hydroxycarbofuran, free or conjugated (Table 2). Oral toxicity tests using rats suggest that carbofuran and 3-hydroxycarbofuran are toxicologically similar (McCarthy, 1975; Ferguson *et al.*, 1984). The oral LD_{50} in rats of carbofuran is in the range 8-14 mg/kg, and that of 3-hydroxycarbofuran is 18 mg/kg (McCarthy, 1975). Other major metabolites of carbofuran are less toxic to mammals, with oral rat LD_{50} values in the range of 69 mg/kg to 2200 mg/kg (McCarthy, 1975).

ENVIRONMENTAL CONCENTRATIONS

Dislodgeable Foliar Residues

Dislodgeable foliar residue (DFR) is defined as the pesticide residue that can be removed from both sides of treated leaf surfaces using an aqueous surfactant. DFR is assumed to be the portion of an applied pesticide available for transfer to humans from leaf and other vegetative surfaces. Measurements of DFR can be used, along with an appropriate transfer coefficient (TC), to estimate the amount of pesticide adhering to clothing and skin surfaces following entry into a previously treated field. The DFR is reported as residue per leaf area ($\mu g/cm^2$).

DFR data from studies involving crops where carbofuran is likely to be used in California are summarized in Table 3. In most studies, 3-hydroxycarbofuran residues were analyzed along with carbofuran; the "Total DFR" column in Table 3 includes carbofuran and 3-hydroxycarbofuran. In general, 3-hydroxycarbofuran residues were small compared to carbofuran, but were included in the total DFR estimate because toxicity of the two compounds is similar (Gupta, 1994), which suggests they are of equal concern.

Table 2. Major Metabolites of Carbofuran (^{14}C Label on Aromatic Ring)

Metabolites	Bile Duct	Urine				
	(a)	(b)	(c)	(d)	(e)	(f)
3-Hydroxycarbofuran	60	15.8	14.8	45	27.7	27.9
3-Ketocarbofuran phenol	5.2	40.8	50.5	1.3		
Carbofuran phenol	3	15.2	21.1	17.7		
3-Hydroxycarbofuran phenol	1.1	14.7	1.4			
3-Ketocarbofuran	0.0	1.2		3.4		
Unknown	29	5.9	8.1		62.2	63.8

[a] Marshall and Dorough (1979): single oral dose of 0.1 mg/kg (1 x 10^6 disintegrations per minute; dpm); within 24 hours, 28.1% of dose was detected via cannulation of bile duct. Of the bile fraction detected via cannulation, 98.3% was recovered as H$_2$O soluble and 1.7% was recovered as organosoluble.

[b] Marshall and Dorough (1979): single oral dose of 0.1 mg/kg (1 x 10^6 dpm); within 48 hours, 65.4% of dose was detected in the urine. Of the urine-collected fraction, respectively, 93.6% and 6.4% were recovered as H$_2$O soluble and as organosoluble.

[c] Dorough (1968): single oral dose of 4 mg/kg (0.07 μg/mmole, 200 counts per minute (cpm)/μg); urine collected over 72 hours. Unknown is sum of water solubles (remaining ^{14}C materials from H$_2$O fraction after acid treatment and extraction with chloroform) + Unknown III.

[d] Metcalf *et al*. (1968): Two 1-hr fasted male mice, each treated with single oral dose of 2 mg/kg [0.1% (w/v) 4,5,6-^{3}H-labeled carbofuran]. Percentage calculated using cpm for each metabolite divided by total cpm. Within 24 hours, one mouse had excreted 37% whereas the other mouse had excreted 67% of the administered radiolabeled dose in the urine.

[e] Ferguson *et al*. (1984): single oral dose of 50 μg/kg [carbonyl-^{14}C (23.7 mCi/mmole)]. The values represent the sum of the H$_2$O + organic soluble fractions. Of the fraction collected from the urine, 67% was recovered as H$_2$O soluble and 25% was recovered as organosoluble. The sum of the unidentified and unextractable residues is unknown.

[f] Ferguson *et al*. (1984): single intravenous (lateral tail vein) dose of 50 μg/kg [carbonyl-^{14}C (23.7 mCi/mmole)]. The values represent the sum of the H$_2$O + organic soluble fractions. Of the urine collected fraction, 69% recovered as H$_2$O soluble and 25% recovered as organosoluble. Unknown is the sum of the unidentified and unextractable residues.

DFR values shown in Table 3 and used in exposure estimates were back-calculated from equations using study data, as explained in Andrews (2000). Values shown in the "Total DFR" column of Table 3 were calculated at the REI for each crop (the crops listed in Table 3, except corn and cotton receiving foliar applications under Section 18 emergency exemptions, all have an REI of 48 hours); the DFR for potatoes was used for the acute exposure estimates of potato scouts, and the DFR for field corn was used for the acute exposure estimates of scouting in corn (see Exposure Assessment section). In Table 3 and in subsequent discussion, Day 0 refers to the day of application, Day 1 is the first post-application day, and subsequent post-application days are similarly identified. The log-linear regression model was used fit the data (Andrews, 2000), using the following equation: $\ln DFR_t = \ln (DFR_0) - kt$. In this equation, k is the slope of the log-linear, first-order dissipation curve and t represents the time interval (days). As shown in Table 3, the half-life of carbofuran residues on foliage (along with its major metabolite, 3-hydroxycarbofuran) ranged from approximately 2.1 to 11.5 days.

Table 3. Dissipation of Carbofuran on Selected Crops [a]

Crop	Location	Initial DFR [b] (μg/cm^2)	Total DFR at REI [c] (μg/cm^2)	Half-Life (Days) [d]
Cotton [e]	Arizona	5.76	0.057	2.1
Field Corn [f]	Minnesota [g]	0.181	0.000	2.4
Field Corn [f]	Missouri	0.101	0.003	3.0
Field Corn [h]	Contra Costa County, California	0.691	0.330	11.5
Grapes [i]	Madera County, California	0.87	0.58 [j]	3.2
Grapes [i]	Napa County, California	1.17	0.88 [j]	5.2
Grapes [i]	Fresno County, California	1.15	0.85 [j]	4.0
Potato [k]	Idaho	0.994	0.186	4.0

[a] Carbofuran applied as Furadan® 4F liquid formulation, mixed with water. Application rate was 1.0 lb AI/acre (1.1 kg AI/ha) in all studies shown. Studies meet acceptability criteria described in Iwata *et al.* (1977) and U.S. EPA (1996a). Residues dislodged with surfactant solution, unless otherwise stated.

[b] Measured on Day 0 (day of application). Includes carbofuran residues alone.

[c] Calculated DFR at expiration of restricted entry interval (REI; 48 hours for most crops, 14 days for corn and cotton receiving foliar applications). Includes summed carbofuran and 3-hydroxycarbofuran residues, which are anticipated to contribute about equally to toxicity. Values calculated using ln DFR$_t$ equation shown in footnote [d].

[d] Half-life calculated from the following equation: $T_{1/2} = (\ln 0.5)/k$, where k is the slope of the linear regression generated from study data (t is the sample time in days): $\ln DFR_t = \ln (DFR_0) - kt$ (Andrews, 2000).

[e] Ware *et al.* (1978); application with tractor-driven groundboom sprayer. Residues dislodged with water.

[f] Liu (1987); aerial application (data followed two applications, four weeks apart).

[g] Rain occurred daily from Day 6 through Day 12.

[h] Leppert (1986); aerial application (data followed two applications, two weeks apart).

[i] Serat (1978); application method not specified (data followed three applications, 26 to 33 days apart).

[j] Includes carbofuran residues alone (3-hydroxycarbofuran not tested).

[k] Barros and Dow (1998); application with groundboom sprayer (data followed three applications, one week apart). Rain occurred during the study, but days with rain events were not specified.

Of the crops listed in Table 3, foliar applications are allowed in California only on potatoes and on field corn that has not received post-plant soil applications, and cotton under Section 18 emergency exemptions. Barros and Dow (1998) reported DFR results following three groundboom applications made at weekly intervals to a potato field, each at 1.0 lbs AI/acre (1.1 kg AI/ha). Although this study was generally well-conducted, because of rainfall occurring during the study, residues were potentially washed from foliage between application and completion of sampling. However, as most California potatoes are grown in winter (Mayberry, 2000), conditions during the study are similar to those that would be anticipated for this crop in California. DFR data from this study were used to estimate exposure of workers scouting potatoes (see Exposure Assessment section). But other crops that might receive foliar applications, such as corn and alfalfa, can be grown in summer, when rain events are rare. Another scenario is needed for these crops. Examination of Table 1 shows that the crop receiving the most carbofuran use is alfalfa (in contrast, carbofuran is rarely used on field corn or sweet corn, suggesting that seasonal and annual exposures would be unlikely in these crops). Although a DFR dissipation study has not been done for carbofuran in alfalfa, other data are available that can be used to estimate exposure to workers reentering treated alfalfa fields.

As part of a large study of pesticide residues encountered by reentering fieldworkers on several crops, Hernandez *et al.* (2002) collected and analyzed 1,003 foliar samples in fifteen counties in

California's Central Valley and coastal regions. DFR samples were collected at the expiration of the REI following known pesticide applications. Carbofuran was detected in 21 out of 27 samples of alfalfa and in 57 out of 74 samples of cotton. Alfalfa leaves were sampled 48 to 60 hours (i.e., within 12 hours of the expiration of the 48-hour REI) following carbofuran applications of 0.25 – 0.5 lbs AI/acre (0.28 – 0.56 kg AI/ha) to fields in Imperial County in March 2001. The overall mean DFR on alfalfa reported by Hernandez *et al.* (2002) was 0.510 $\mu g/cm^2$. This DFR was used in calculating acute exposure of alfalfa scouts, after first adjusting it because none of the fields sampled by Hernandez *et al.* (2002) had received the maximum application rate allowed on alfalfa (Hernandez, 2001). The DFR was multiplied by the ratio of this rate (1.0 lb AI/acre) to the weighted average rate (0.44 lb AI/acre) used, to get an adjusted DFR of 1.16 $\mu g/cm^2$. Dissipation of the DFR was estimated using the mean dissipation of carbofuran in all studies done in California, which is 6.0 days (range 3.2 to 11.5). The adjusted DFR at Day 2 and the estimated half-life can be used to solve for the remaining variables in the equations given in Footnote d of Table 3. Doing so gives a DFR equation of $\ln DFR_t = 0.928 - 0.116t$, which can be used to calculate DFR for long-term exposure estimates for alfalfa scouts (see Exposure Assessment section).

Although foliar applications of carbofuran are not currently allowed on cotton (the most recent Section 18 emergency exemption was issued in 2003), reentry exposure into cotton was considered in this EAD as emergency exemptions could be issued in the future. DFR data from Ware *et al.* (1978) were used in exposure estimates. These data were collected in Arizona; cotton in California is grown under similar conditions. Data collected in California are available to compare with DFR results reported by Ware *et al.* (1978). To supplement the DFR sampling at the expiration of the REI, DPR collected additional cotton foliage samples 3 to 14 days following carbofuran applications of 0.25 lbs AI/acre (0.28 kg AI/ha) to 35 fields in Fresno, Madera, Colusa and Yolo Counties in July-September 2001 (Curtis, 2002). The study was not designed to measure carbofuran dissipation; initial DFR samples were not collected, and just eight of the 35 fields were repeatedly sampled. In Fresno and Madera counties, which are adjacent to one another, the mean DFR at Day 2 was 0.218 $\mu g/cm^2$; the mean DFR at Day 7 was 0.087 $\mu g/cm^2$; and the mean DFR at Day 14 was 0.078 $\mu g/cm^2$ (Curtis, 2002). Comparison of the Day 14 value from Curtis (2002) to the value estimated from data shown in Ware *et al.* (1978)—in which DFR at Day 14 was 0.057 $\mu g/cm^2$—suggests that the Day 14 DFR value based on Ware *et al.* (1978) is in the range of residues to which workers might be exposed.

Carbofuran total (not dislodgeable) foliar residues were determined following applications to strawberries (Archer *et al.*, 1977) and alfalfa (Shaw *et al.*, 1969; Archer, 1976; Draper *et al.*, 1981). Three studies were available in which carbofuran residues were monitored as breakdown products following carbosulfan application (Markle, 1982; Iwata *et al.*, 1983; Nigg *et al.*, 1984); none of these studies was used to estimate exposure following applications of carbofuran.

Ground and Surface Water

A Public Health Goal of 1.7 $\mu g/L$ was developed for carbofuran in drinking water by the Office of Environmental Health Hazard Assessment (Jowa, 2000). California has set a Maximum

Contaminant Level (MCL) of 18 µg/L (22 CCR 64444). The federal MCL is 40 µg/L (U.S. EPA, 2002)

Carbofuran has been detected only occasionally in routine surface and ground water monitoring. Wangsness (1997) reported in a United States Geological Survey (U.S.G.S.) draft document that in the U.S. surface water concentrations of carbofuran ranged from less than 0.003 to 9.0 µg/L; ground water carbofuran concentrations ranged from less than 0.003 to 2.8 µg/L. The highest carbofuran concentration found in either surface or ground water in California was 0.149 µg/L at a site in the lower Colorado River basin. DPR's Surface Water Database contains records of detections every year between 1991 and 1998, with a total of 279 detections in 3007 samples collected as of December 2002 (Evert, 2002).

Ganapathy *et al.* (1997) reported no detections of carbofuran in 224 surface water samples taken in the watersheds of the Merced, Sacramento, Salinas, and Russian rivers between 1993 and 1995 (detection limit: 0.05 µg/L); one sample, from the Merced watershed, was positive for the carbofuran metabolite, 3-hydroxy carbofuran (0.18 µg/L). Nordmark (1998) sampled the Sacramento River watershed from December 1996 through March 1997 without detecting carbofuran or its metabolites (detection limit: 0.05 µg/L). Jones *et al.* (2000) sampled several rivers in northern California in 1998 and 1999 without detecting carbofuran (detection limit: 0.05 µg/L; metabolites were not monitored).

Carbofuran was detected in three studies designed to measure concentrations in runoff from rice fields and receiving water bodies. Nicosia *et al*. (1990) sampled runoff water from three rice and three sugar beet fields in 1988. In rice field runoff, maximum carbofuran concentrations occurred within the first 26 days following flooding and ranged 21 – 33 µg/L. In 1995, Bennet *et al.* (1998) measured carbofuran concentrations in irrigation drain and slough water receiving runoff from rice fields, as well as in the Sacramento River. Carbofuran was detected in several irrigation drain samples collected in May through July, with concentrations ranging 0.12 – 0.70 µg/L, and in four slough water samples with concentrations ranging 0.37 – 0.57 µg/L (Bennet *et al*., 1998). Newhart and Bennett (1999) reported on a rice pesticide monitoring study at the same locations in April - June 1999, with sampling timed to coincide with anticipated peak pesticide concentrations. Carbofuran was detected in four irrigation drain samples and one slough water sample, with peak concentrations of 3.6 and 0.77 µg/L, respectively. Carbofuran was not detected in any Sacramento River sample in either of the latter two studies; both had detection limits of 0.10 µg/L (Bennett *et al*., 1998; Newhart and Bennett, 1999).

Air

California has laws that limit ambient air concentrations of pesticides, including the Toxic Air Contaminants Act (California Health and Safety Code, Sections 39650-39761), which codified the state program to evaluate and control toxic air contaminants (TAC). A pesticide is placed on the TAC list if its concentrations in ambient air have been determined to be within an order of magnitude of the concentration determined to cause human health effects (3 CCR 6890). Carbofuran is a TAC candidate (Shibamoto *et al*., 1993). Carbofuran concentrations have been monitored in the ambient air during peak application season and in the air surrounding application sites.

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Ambient Air

In 1995, the Air Resources Board (ARB) of the California Environmental Protection Agency did ambient air monitoring in Imperial County in southern California (ARB, 1995). The ARB collected air samples during a four-week interval, from February 14 through March 10, at four sites near anticipated carbofuran applications (although whether applications actually occurred near all sampling locations during the sampling interval was not reported) and an urban (background) site. The ambient sites were rural areas in the following locations: one in Calipatria (Site C; duplicate samples collected at this site); one at the Meadows Union School between El Centro and Holtville (Site M); one in Heber (Site H); and one northeast of El Centro at an Air Pollution Control District monitoring station (Site PM). The background site was in El Centro (Site EC). Except for one site that was at ground level (Site PM; 1.5 m above ground), all samples were taken on roof tops approximately 5 m above ground. Sample devices consisted of 30 ml XAD-4 resin in Teflon holders, connected to air pumps with Teflon tubing; air pumps were calibrated to 14.7 L/min (ARB, 1995). Quality assurance included the use of laboratory spikes, field spikes (recovery 106% $\pm$ 7%), one method blank, one field blank, collocated samples at one site, and background samples prior to the application; all were acceptable (ARB, 1995). Monitoring results are summarized in Appendix 1. Of the 82 samples, 55 were below the limit of detection (LOD) of 0.25 µg/sample (approximately 0.012 µg/m^3). No limit of quantification (LOQ) was reported by ARB (1995); concentrations were reported if greater than the LOD. The same practice is followed in this EAD. Concentrations in the remaining samples ranged from 0.014 to 0.11 µg/m^3 (ARB, 1995; Kollman, 1995).

In 1996 and 1997, the U.S.G.S. monitored atmospheric concentrations of several pesticides, including carbofuran, at three locations in Sacramento County (Majewski and Baston, 2002). Two of the sites were rural, at airports northwest and southeast of Sacramento (samplers were about 3 m above ground); the third site was in downtown Sacramento (about 10 m above ground). The rural sites were approximately 10 and 20 miles (16 and 32 km) northwest and southeast, respectively, of the downtown site. Sample devices consisted of 119-cm^3 polyurethane foam plugs (mean density = 0.043 g/m^3) in Teflon cartridges, connected to high-volume blowers flowing at approximately 100 L/min (Majewski and Baston, 2002). Weekly whole-air (particulates were not filtered out), composite samples were collected at each site throughout the study. Sampling was triggered when 15-min mean wind speeds were >1 m/sec in a northerly or southerly direction, and continued until the directional wind speed decreased below the trigger velocity; maximum sampling was 20 min/hr. Carbofuran was detected just once at each of the rural sites (concentrations: 0.00033 and 0.00338 µg/m^3); both samples were collected when the wind was from the south (detection limit 0.00015 µg/m^3). In contrast, carbofuran was detected several times in the downtown Sacramento site; it was detected in 32.4% of samples collected when the wind was blowing from the south, and in 19.7% of samples collected when the wind was out of the north. Concentrations of carbofuran in samples collected from the downtown site ranged 0.00008 – 0.013 µg/m^3, and are summarized in Appendix 1. Average detected carbofuran was 0.0017 and 0.0024 µg/m^3 for samples collected during south and north winds, respectively (Majewski and Baston, 2002). Because carbofuran has no registered use in urban settings, the pattern of detections is puzzling, and Majewski and Baston (2002) were unable to provide an explanation. The northern rural sampling site is surrounded by areas where rice is cultivated, and the southern rural site is in an area dominated by pastureland,

vineyards and native vegetation. There are some areas where grain and hay crops are grown both north and south of the downtown site; it's possible carbofuran applications to alfalfa occurred in these areas.

Ambient air concentrations of carbofuran were also greater at an urban than a rural site in a study done in the Rhine Valley in France in 1993 – 1994, probably because the urban site was located within a larger agricultural area (Sanusi *et al*., 2000). The rural site was southeast of the small city of Colmar, in a region where most crops were either corn or vine crops; the urban site was a "polluted city," Strasbourg, which was largely industrial but with a larger surrounding agricultural area (the valley is narrower at Colmar than at Strasbourg). A total of eight 24-hour samples were collected at Colmar; nine samples were collected at Strasbourg. Sample devices consisted of 20 ml XAD-4 resin in Teflon holders, connected to a high-volume sampler; particulates were collected on glass fiber filters (30 cm diameter). Sampler flow rates varied, but $140 – 700 \text{ m}^3$ air was collected. Carbofuran concentrations at Colmar ranged from < 0.000228 – 0.0081 μg/m^3, with a mean of 0.00285 μg/m^3. Concentrations at Strasbourg ranged from $0.00143 – 0.02897 \text{ μg/m}^3$, with a mean of 0.01259 μg/m^3 (Sanusi *et al*., 2000).

Application Site Air

Two studies are available of airborne carbofuran associated with applications. In 1993, the ARB measured carbofuran concentrations in air during a groundboom application of carbofuran in Imperial County in California (ARB, 1994).   The air monitoring stations were located approximately 20 m from the N, E, W, and S, respectively, edges of a 70-acre (28-ha) alfalfa field receiving carbofuran applications at a rate of 0.3 lb AI/acre (0.34 kg AI/ha). Sample devices consisted of 30 ml XAD-4 resin in Teflon holders, connected to air pumps with Teflon tubing; air pumps were calibrated to 16.2 L/min. The application took place on March 31 between 10:00 and 11:00 AM. Samples were collected from the day of application (March 31) through April 2. Quality assurance included the use of laboratory spikes (recovery 96% $\pm$ 5%), one method blank, one field blank, and seven duplicate samples; all were acceptable (ARB, 1994). Of the 35 samples, eleven were below the LOQ of 0.3 μg/sample (approximately 0.014 μg/m^3 for a 24-hour sample). Concentrations in the remaining samples ranged from 0.15 to 0.66 μg/m^3 on March 31, and from 0.03 to 0.21 μg/m^3 on April 1-2 (ARB, 1994).

Table 4 summarizes air concentrations during the monitoring periods. A time-weighted average (TWA) concentration was calculated for the first day, starting with the hour during which the application occurred (21 hours of monitoring).   This TWA value was used in estimating bystander exposures (see the Exposure Assessment section).

In a study conducted outside California, Draper *et al.* (1981) collected air samples during and 2 hours following aerial carbofuran applications to alfalfa fields in Utah. The two fields, 20 and 40 acres (8 and 16 ha) each, were treated with Furadan® 4F at a rate of 0.5 lbs AI/acre (0.56 kg AI/ha). Wind speeds during both applications were less than 5 mph (8 km/hr). A total of eleven air samples were collected from five locations, using high-volume air samplers. Samplers were located within the field, or up to 600 m away (sampler heights were not stated). Each sample device consisted of 120 ml XAD-4 resin in a 1.8-cm bed, connected to a high-volume sampler, and particulates were collected on a glass fiber filters. Sampler flow rates were 230 – 710 L/min. Both the air sampling locations and the aerial applications were oriented in an E-W direction,

and the wind direction was W-SW for both fields during sampling. No carbofuran was detected in samples collected 200 – 600 m from application sites. At a sampler located 25 m E of the 20-acre field, carbofuran concentrations ranged 0.7 – 3.3 μg/m^3. At a sampler located 42 m NE of the 40-acre field, carbofuran concentrations ranged 0.17 – 0.22 μg/m^3 (Draper *et al.*, 1981). These data were not used in estimating bystander exposure because of the inability reported by Draper *et al.* (1981) to distinguish between airborne concentrations and fallout from the aerial spray (i.e., air samplers might have been directly sprayed).

Table 4. Carbofuran Concentrations (μg/m^3) Twenty Meters from an Alfalfa Field Receiving an Application by Groundboom [a]

Date and time of monitoring	West	North [b]	East	South	Wind Speed [c]	Wind Direction
March 31, 1993, 0800-0930 [d]	ND [e]	ND	ND	ND	1	NE
March 31, 1993, 1000-1100 [f]	0.29	ND	0.66	ND	2	SE
March 31, 1993, 1100-1400	0.49	0.28	0.15	ND	3	SE/SW
March 31, 1993, 1400-1730	0.53	0.60	0.27	ND	5	SE
March 31, 1993, 1730-2100	0.26	0.21	0.15	ND	2	SE
March 31-April 1, 1993, 2100-0700	0.031	0.08	0.24	0.11	2	W/NW
24-hour Time-Weighted Average [g]	0.23	0.22	0.22	0.08	NA	NA
April 1-2, 1993, 0700-0600	0.035	0.06	0.12	0.05	8	W/N/S/E

[a] All stations were approximately 20 m from the edge of field (ARB, 1994). Concentrations calculated by dividing carbofuran measured in sample by sample volume. Sample pumps were calibrated to run 16.2 L/min.
[b] Mean of two stations.
[c] Wind speed in miles/hour. NA: not applicable.
[d] Background air monitoring before application.
[e] Not detected, below limit of quantification (LOQ) of 0.3 μg/sample.
[f] Air monitoring during application. Subsequent measures are post-application.
[g] Time-weighted average (TWA) concentration over first 24 hours, beginning with application at 10:00 AM and ending with sample completed 20 hours post-application. Samples taken during 21 hours were used as an approximation for the 24-hour TWA. For ND samples, ½ LOQ was used in calculations.

EXPOSURE ASSESSMENT

Handler and reentry exposure to carbofuran is anticipated to be limited to workers engaged in agricultural tasks. No residential, industrial or institutional use of carbofuran is permitted by its label. However, residents and bystanders may be exposed to airborne carbofuran, as suggested by results of air monitoring studies summarized in the Environmental Concentrations section. Significant exposure scenarios are discussed in the following sections.

For each scenario, estimates are provided for acute (defined in this EAD as exposures lasting from less than a day to short-term intervals up to one week) and intermediate to long-term (seasonal, annual, and lifetime) exposures. Seasonal exposure is defined as a period of frequent exposure lasting more than a week but substantially less than a year, whether the exposure is constant or intermittent during the period. Annual exposure integrates all exposure periods

during the year. Lifetime exposures integrate all exposure periods over several years. For occupational scenarios, two assumptions are used in calculating lifetime exposure, that the average life expectancy is 75 years (U.S. Bureau of the Census, 1995), and that a person does the same job for 40 years.

Surrogate data from the PUR were used to estimate intervals for seasonal and annual exposures. Carbofuran is registered for use on several different crops, and for some crops repeated use is allowed within a growing season, suggesting that handlers may potentially be exposed throughout the year. Repeated exposures are more likely for professional applicators and their employees, as these handlers can make the same treatment for several growers. However, PUR data show that for many crops carbofuran use does not occur throughout the year, and that for others relatively few applications are made. It is reasonable to assume that an individual handler is less likely to be exposed to carbofuran during these relatively low-use intervals. Thus, rather than assume that handlers are exposed throughout the year, annual use patterns are plotted based on monthly PUR data. Annual exposure to carbofuran is assumed to be limited to the months when use is relatively high (defined as 5% or more of annual use each month). Seasonal exposure intervals are assumed to be the longest contiguous period during which monthly use is at least 5% of annual total; seasonal use may involve fewer months than annual use.

Handlers

Exposure Monitoring

One study was available in which handler exposure to carbofuran was monitored. Hussain *et al.* (1990) monitored prairie grain farmers in southern Alberta, Canada, during groundboom applications of Furadan® 480F in wheat at application rates ranging 0.26 – 0.70 lb AI/acre (0.29 – 0.79 kg AI/ha). Four individuals were mixer/loader/applicators (M/L/As) and two were applicators, although results were not reported in an activity-specific way. Each participant in the study wore long pants, long-sleeve shirt, wool socks, a cap, and leather or rubber boots. During mixing, the M/L/As wore disposable Tyvek® coveralls, rubber gloves, and a MSMA approved respirator with dual organic vapor cartridges with dust filters. During spraying, M/L/As and applicators did not wear rubber gloves. Potential dermal exposure was measured using Tegaderm® patches (10 cm^2) placed both on the skin beneath the work clothing and outside of the coveralls, and isopropanol rinses of wrists and hands. Potential inhalation exposure was measured using polyurethane foam plugs inserted in Plexiglass columns connected to suction pumps. In addition to potential dermal and inhalation exposures, medical baseline data, including both blood and urine samples, were collected one week before the spraying season began. Subsequent 24-hour urine collections were done for 4 days after individuals began spraying, and blood samples were also taken every 24 hours for 4 days.

During the monitoring period, the amount of AI handled per participant ranged from 2.11 to 25.3 lbs (0.96 to 11.5 kg). The areas treated ranged 6 – 72 hectares (14.8 – 178 acres) and the application time ranged from 34 minutes to 5 hours. Samples were analyzed for carbofuran only, not for metabolites. The mean estimated total exposure to the volunteer handlers was 574.4 μg AI/lb handled (range, 33.8 – 2,585.6 μg AI/lb handled). Average inhalation exposure was 0.15% of total exposure, including samples from two participants in which carbofuran was nondetectable (detection limit = 0.01 ppm). Most of the dermal exposure (87%) occurred on

hands and wrists. The mean amount of carbofuran detected in the urine was 12.5 μg/lb AI handled, or 6.6% of the total exposure per volunteer. No cholinesterase inhibition was observed in whole blood or plasma. However, while samples were maintained on ice prior to analysis, they were analyzed 3 – 5 days after collection, and evidence from other studies suggests that the storage precaution may not have been sufficient to prevent reactivation of inhibited cholinesterase (Gupta, 1994). No changes were detected in any of the 30 other hematology and blood chemistry parameters measured (Hussain *et al*., 1990).

This study was unacceptable for estimating exposure because of the small sample size, and because exposure results were not related to activities. Data from this study were not used in estimating handler exposure, although in the Exposure Appraisal section these data were compared to exposure estimates from surrogate data.

Exposure Estimates Using Surrogate Exposure Monitoring Data

As no acceptable studies were available for assessment of handler exposure, estimates were based on surrogate data from the Pesticide Handler Exposure Database (PHED, 1995). PHED was developed by the U.S. EPA, Health Canada and the American Crop Protection Association to provide non-chemical-specific pesticide handler exposure estimates for specific handler scenarios. It combines exposure data from multiple field monitoring studies of different AIs. The user selects a subset of the data having the same or a similar application method and formulation type as the target scenario. The use of non-chemical-specific exposure estimates is based on two assumptions: (1) that exposure is primarily a function of the pesticide application method/equipment and formulation type and not of the physical-chemical properties of the specific AI; and (2) that exposure is proportional to the amount of AI handled.

PHED has limitations as a surrogate database (Powell, 2002). It combines measurements from diverse studies involving different protocols, analytical methods and residue detection limits. Most dermal exposure studies in PHED use the patch dosimetry method of Durham and Wolfe (1962); residues on patches placed on different parts of the body are multiplied by the surface area of the body part to estimate its exposure. These partial estimates are then summed to provide a total body exposure estimate. Some studies observed exposure to only selected body parts such as the hands, arms and face. As a consequence, dermal exposure estimates for different body parts may be based on a different set of observations. Further, for some handler scenarios, the number of matching observations in the PHED is so small that the possibility they do not represent the target scenario is substantial. Due to the degree of uncertainty introduced by using this surrogate data, DPR calculates upper confidence limits on the exposure statistics to increase the confidence in the estimates of exposure.

When using surrogate data from PHED to estimate acute exposure, DPR uses the 90% upper confidence limit (UCL) on the 95th percentile. The confidence limit is used to account for some of the uncertainty inherent in using surrogate data and to increase our confidence in the estimate. (Confidence limits on percentiles, also called tolerance limits, are described by Hahn and Meeker (1991).) Estimating the confidence limit requires knowing the mean and standard deviation. PHED reports the mean of total dermal exposure, but only the coefficients of variation for separate body regions. Because the sample sizes per body region differ and because the correlations among body regions are unknown, the standard deviation of total dermal

exposure cannot be calculated. In order to approximate the confidence limit for the 95th percentile, DPR makes the assumption that total exposure is lognormally distributed across persons and has a coefficient of variation of 100 percent. The method of approximation is described in Powell (2002), and uses the fact that in any lognormal distribution with a given coefficient of variation, the confidence limit for the 95th percentile is a constant multiple of the arithmetic mean. The value of the multiplier depends only on sample size. If the sample size is between 20 and 119, the multiplier is 4; if it is between 12 and 19, the multiplier is 5. Estimated exposures from PHED are summarized in Table 5, along with statements of assumptions used in exposure calculations and results of PHED subsets. Numbers of observations are given in the PHED reports (Appendices 2-6); for non-hand dermal exposure, the median number of observations over body regions is used as the sample size.

When using surrogate data to estimate intermediate or long-term exposure, DPR uses the 90% UCL on the arithmetic mean. The 90% UCL is used for the reasons listed in the previous paragraph. If the sample size is between 6 and 14, the multiplier is 2; if it is greater than 15, the multiplier is 1.

Groundboom Applications.

Significant exposure scenarios involving groundboom applications are M/L and applicator. For M/L, use of a closed system was assumed, based on California requirements, and M/L were assumed to wear the clothing and PPE listed on product labels. A 90% protection factor was applied to the inhalation PHED results for use of a respirator (Appendix 2). Applicators were assumed to use clothing and PPE required by product labels and California regulations. The groundboom applicator scenario included use of either truck or tractor, and an open cab was assumed as there is no requirement for a closed cab. Two 90% protection factors were applied to PHED results for applicators (Appendix 3): to hand exposure for use of gloves (Aprea *et al.*, 1994), and to inhalation exposure for use of a respirator (NIOSH, 1987). The protection factor for gloves was needed because the applicator PHED scenario with gloves gave results with insufficient numbers of high-quality observations, and the scenario used did not include gloves.

It was assumed that 40 acres/day (16 ha/day) would be treated (Haskell, 1998). The application rate, 10 lbs AI/acre (11 kg AI/ha), is the rate allowed for field-grown ornamentals to which carbofuran is applied as a high volume spray or drench, which is then irrigated immediately after treatment to move spray or drench into the root zone (Special Local Need registration, CA SLN No. 830058).

As shown in Table 5, the total Acute Absorbed Daily Dosage (Acute ADD) estimate for M/L was 0.224 mg/kg/day. For the applicator scenario, the Acute ADD estimate was 0.318 mg/kg/day. Assuming that a M/L/A spends part of a workday mixing/loading and part making the application, exposure of the M/L/A should be less than the applicator exposure and greater than that of the M/L.

Table 5. Data Used in Estimates of Exposure for Workers Handling Carbofuran and Acute Pesticide Handler Exposure Estimates

Scenario [a]	# [b]	Acute Exposure [c] (µg/lb AI handled)		Long-term Exposure [c] (µg/lb AI handled)		Acute ADD [d] (mg/kg/day)		
		Dermal	Inhalation	Dermal	Inhalation	Dermal	Inhalation	Total
GB [e]								
M/L	2	77.3	0.512	19.3	0.128	0.221	0.003	0.224
A	3	102	4.72	25.5	1.18	0.291	0.027	0.318
Aerial [f]								
M/L	2	77.3	0.512	19.3	0.128	0.552	0.008	0.560
A	4	891	2.86	297	1.15	6.36	0.041	6.40
F	5	152	0.800	25.5	1.18	1.09	0.011	1.10
C [g]								
M/L	2	77.3	0.512	19.3	0.128	1.16	0.015	1.18
LPHW [h]								
M/L/A	6	9,480	137	3,160	45.6	0.002	0.00005	0.002
Dip [i]								
M/L	2	77.3	0.512	- -	- -	0.002	0.00003	0.002
A	7/8	- -	- -	- -	- -	1.29	0.001	1.29

[a] Abbreviations: A = Applicator. C = Chemigation F = Flagger GB = Groundboom. LPHW =Low pressure handwand. M/L = Mixer/loader. M/L/A = Mixer/loader/applicator.

[b] Appendix number. Handlers were assumed to wear gloves as specified on product labels, except aerial applicators (exempt from wearing gloves under California regulation). Mixing/loading assumed to require closed system, except small quantities that can be handled with low pressure handwand.

[c] Acute exposures last from less than a day to short-term intervals up to one week; long-term exposure estimates cover longer intervals, including seasonal, annual and lifetime. Dermal and inhalation exposure calculated from surrogate data using the Pesticide Handlers Exposure Database (PHED, 1995), except for dip/slurry applicator. Values from PHED were rounded to three significant figures.

[d] Acute Absorbed Daily Dosage (acute ADD) is an upper-bound estimate calculated from the acute exposure. Application rate is maximum rate on product labels, which varied for each scenario; acres treated per day varies by scenario. Estimates were rounded to three significant figures. Calculation:

Acute ADD = [(acute exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).

Calculation assumptions include: dermal absorption = 50% (Donahue, 1996); body weight = 70 kg (Thongsinthusak, *et al.*, 1993a); inhalation absorption = 100%.

[e] Acute ADD estimates assumed 40 acres (16 ha) treated/day (Haskell, 1998), and a maximum application rate of 10 lbs AI/acre (11 kg AI/ha), maximum rate on field-grown ornamentals.

[f] Acute ADD estimates assumed 1,000 acres (405 ha) treated/day (Haskell, 1998), and a maximum application rate of 1.0 lb AI/acre (1.1 kg AI/ha), maximum rate on alfalfa.
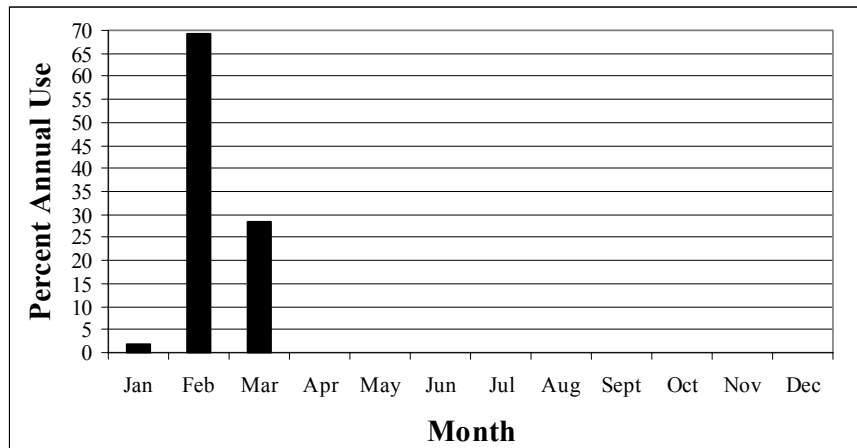
[g] Acute ADD estimates assumed 350 acres (142 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 6.0 lbs AI/acre (6.7 kg AI/ha), maximum rate on post-harvest grapes.

[h] Acute ADD estimates assumed handling of 40 gal/day, containing 0.062 lb AI/100 gal (U.S. EPA, 2001), for a total of 0.025 lb AI/day (0.011 kg AI/day).

[i] Acute ADD estimates assumed handling of 40 gal/day, containing 0.1 lb AI/100 gal (U.S. EPA, 2001), for a total of 4 lb AI/day (1.8 kg AI/day). M/L estimates from PHED. Applicator dermal exposure estimates based on RAGS-E equations (U.S. EPA, 2004a). Applicator inhalation exposure estimates based on SWIMODEL (U.S. EPA, 2003), assuming a saturated carbofuran vapor concentration. See Appendix 7 and Appendix 8 for calculations of applicator exposure estimates.

Groundboom applications are common in row and field crops, such as alfalfa, artichokes, bermudagrass, and cotton. Alfalfa was selected as a representative crop, and all ground applications to alfalfa were assumed to be groundboom applications. Figure 3 summarizes ground applications of carbofuran to alfalfa in Imperial County, based on pounds applied per month for the most recent five years for which data are available, 1999-2003 (DPR, 2005b; queried July 15, 2005). Most carbofuran use on alfalfa during the five-year period occurred in Imperial County.

Figure 3. Ground Applications of Carbofuran to Alfalfa in Imperial County, 1999 – 2003 [a]

[a] Percent calculations based on pounds applied (DPR, 2005b; queried July 15, 2005).

Nearly all applications occurred in the two-month period of February and March (Figure 3). Ground applications to other field crops also tended to occur during two months each year (data not shown), supporting a seasonal and annual estimate of two months. Both seasonal (the longest period of frequent exposure) and annual exposures were assumed to occur during these two months. Estimates of seasonal, annual and lifetime exposures are given in Table 6.

Aerial Applications

Significant exposure scenarios involving aerial applications are M/L, applicator, and flagger. All M/L exposure estimates (in support of groundboom, aerial, and chemigation applications) used the same surrogate PHED data, with the same clothing and PPE assumptions, and the same protection factors were applied to the PHED results. Applicators and flaggers were assumed to use clothing and PPE listed on product labels; this included long-sleeved shirt and pants, shoes plus socks, waterproof gloves, and a respirator. Open cockpits were assumed, as there is no requirement for closed cockpits during applications. A 90% protection factor was applied to inhalation data in PHED results for applicators and flaggers (Appendix 4 and Appendix 5), for use of a respirator (NIOSH, 1987). Also, a 90% protection factor was applied to hand exposure data in PHED results for flaggers for use of gloves (Aprea *et al*., 1994), because flagger PHED scenarios with gloves gave results with insufficient numbers of high-quality observations, and the scenario used did not include gloves. The application rate, 1.0 lb AI/acre (1.1 kg AI/ha), is the maximum rate allowed for alfalfa and foliar applications to field corn, and it was assumed that 1,000 acres/day (405 ha/day) would be treated (Haskell, 1998).

Table 6. Seasonal, Annual, and Lifetime Estimates of Pesticide Handler Exposure to Carbofuran

Scenario [a]	SADD [b] (mg/kg/day)			AADD [c] (mg/kg/day)			LADD [d] (mg/kg/day)		
	Dermal	Inhalation	Total	Dermal	Inhalation	Total	Dermal	Inhalation	Total
GB [e]									
M/L	0.055	0.001	0.056	0.009	0.0001	0.009	0.005	0.0001	0.005
A	0.073	0.007	0.080	0.012	0.001	0.013	0.006	0.001	0.007
Aerial [f]									
M/L	0.138	0.002	0.140	0.023	0.0003	0.023	0.012	0.0002	0.012
A	2.12	0.016	2.14	0.354	0.003	0.357	0.189	0.001	0.190
F	0.271	0.003	0.274	0.045	0.001	0.046	0.024	0.0003	0.024
C [g]									
M/L	0.290	0.004	0.294	0.072	0.001	0.073	0.039	0.001	0.040
LPHW [h]									
M/L/A	0.0006	0.00002	0.0006	0.0001	0.00001	0.0001	0.0001	0.000002	0.0001

[a] Abbreviations: A = Applicator. C = Chemigation F = Flagger GB = Groundboom. LPHW = Low pressure handwand. M/L = Mixer/loader. M/L/A = Mixer/loader/applicator.

[b] Seasonal Average Daily Dosage is a 90% upper confidence estimate calculated from the long-term exposure estimate given in Table 5. Application rate is maximum rate on product labels, which varied for each scenario; acres treated per day varies by scenario. Dermal absorption assumed to be 50% (Donahue, 1996). Inhalation absorption assumed to be 100%. Body weight assumed to be 70 kg (Thongsinthusak *et al*., 1993a). Calculation: SADD = [(long-term exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).

[c] Annual Average Daily Dosage = SADD x (annual use months per year)/(12 months in a year). Annual use estimates vary for each scenario.

[d] Lifetime Average Daily Dosage = AADD x (40 years of work in a lifetime)/(75 years in a lifetime).

[e] Estimates assumed a maximum application rate of 10 lbs AI/acre (11 kg AI/ha), maximum rate on field-grown ornamentals. Assumed 40 acres (16 ha) treated/day (Haskell, 1998). Seasonal and annual exposures are estimated to occur over two months.

[f] Estimates assumed a maximum application rate of 1.0 lb AI/acre (1.1 kg AI/ha), maximum rate on alfalfa. Assumed 1,000 acres (405 ha) treated/day (Haskell, 1998). Seasonal and annual exposures are estimated to occur over two months.

[g] Estimates assumed a maximum application rate of 6.0 lb AI/acre (6.7 kg AI/ha), maximum rate on post-harvest grapes. Assumed 350 acres (142 ha) treated/day (U.S. EPA, 2001). Seasonal exposure is estimated to occur during a two-month period; annual exposure is estimated to occur over a total of three months.
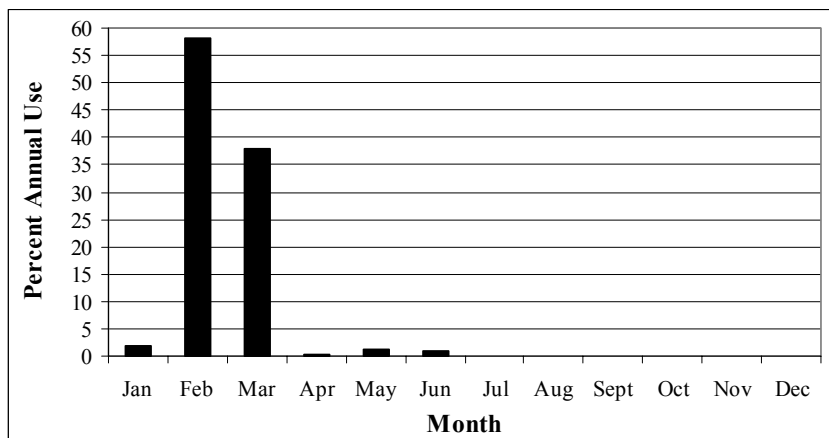
[h] Estimates assumed handling of 40 gal/day, containing 0.000625 lb AI/100 gal (U.S. EPA, 2001), for a total of 0.025 lb AI/day (0.011 kg AI/day). Seasonal and annual exposures are estimated to occur over three months.

The Acute ADD estimates were 0.560 mg/kg/day for M/L, 6.40 mg/kg/day for aerial applicators, and 1.10 mg/kg/day for flaggers (Table 5).

Figure 4 shows percent of annual use based on pounds applied per month for the most recent five years for which data are available, 1999-2003 (DPR, 2005b; queried July 15, 2005). Data from Imperial County, which has the most aerial applications of carbofuran, are summarized in Figure 4. Nearly all applications occurred in the two-month period of February and March. For seasonal and annual exposure estimates, it was assumed that workers were exposed on each

workday for these two months. Estimates of seasonal, annual and lifetime exposure are given in Table 6.

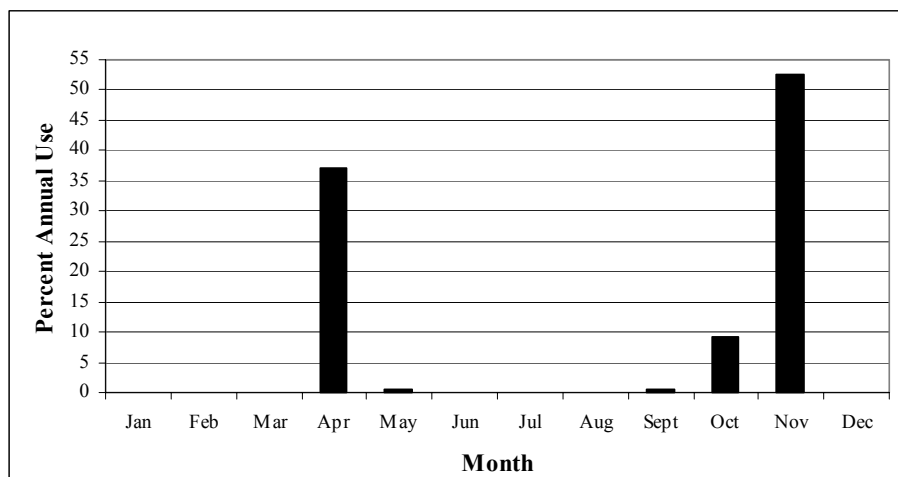**Figure 4. Aerial Applications of Carbofuran in Imperial County, 1999 – 2003 [a]**

[a] Percent calculations based on pounds applied (DPR, 2005b; queried July 15, 2005).

Chemigation (Drip Irrigation)

The significant exposure scenario for chemigation is M/L. No exposure to the applicator is expected during application via drip irrigation (Lavy and Mattice, 1985). For M/L, use of a closed system was assumed, in accordance with California regulations, and M/L were assumed to wear the clothing and PPE listed on product labels. A 90% protection factor was applied to the inhalation PHED results for use of a respirator (Appendix 2). The maximum application rate is 6.0 lbs AI/acre (6.7 kg AI/ha), on post-harvest grapes (Special Local Need registration, CA SLN No. 980012). A default of 350 acres/day (142 ha/day) was assumed (U.S. EPA, 2001). The Acute ADD estimate for M/L in support of chemigation was 1.18 mg/kg/day (Table 5).

Chemigation is used to apply carbofuran to grapes. Figure 5 shows percent of annual use based on pounds applied to grapes per month for the most recent five years for which data are available, 1999-2003 (DPR, 2005b; queried July 21, 2005). All applications were assumed to be made using chemigation, although Section 24(c) labels also allow soil applications using a sprayblade and soil drenching in container-grown grapevines. Data from Monterey County, which has the most applications of carbofuran to grapes, are summarized in Figure 5.

Nearly all applications occurred in April, October, or November (Figure 5). Seasonal exposure was estimated to occur during the two-month interval of October and November (the longest contiguous period during which monthly use was at least 5% of annual total). Annual exposure was estimated to occur during all three months. Estimates of seasonal, annual and lifetime exposure are given in Table 6.

Figure 5. Applications of Carbofuran to Grapes in Monterey County, 1999 – 2003 [a]

[a] Percent calculations based on pounds applied (DPR, 2005b; queried July 21, 2005).

Handwand Applications

The significant exposure scenario is M/L/A. Workers were assumed to use clothing and PPE listed on product labels. A 90% protection factor was applied to inhalation exposure data for use of a respirator (NIOSH, 1987). The maximum application rate for container-grown ornamentals is 2 fluid ounces of Furadan[®] 4F per 100 gallons. Workers were assumed to handle 40 gal/day (U.S. EPA, 2001). The amount of carbofuran handled per day was calculated as follows:

(2 fl oz product/100 gal) x (1 gal/128 fl oz) x (4 lbs AI/gallon) = 0.000625 lb AI/gal.
(0.000625 lb AI/gal) x (40 gal/day) = 0.025 lb AI/day.

The estimated Acute ADD for M/L/A using low-pressure handwands was 0.002 mg/kg/day.

Figure 6 shows percent of annual use based on pounds applied to plants grown in containers in greenhouses and nurseries per month for the most recent five years for which data are available, 1999-2003 (DPR, 2005b; queried July 21, 2005). All applications were assumed to be made using handwands. Data from Del Norte County, which has the most applications of carbofuran to container-grown plants, are summarized in Figure 6.

Figure 6. Applications of Carbofuran in Nurseries and Greenhouses in Del Norte County, 1999 – 2003 [a]

[a] Percent calculations based on pounds applied to plants in containers (DPR, 2005b; queried July 21, 2005).

Dip/Slurry Applications

Product label directions for treating pine seedlings for pales weevils and pitch-eating weevils are as follows: "Apply a 1% (W/W) active Furadan clay slurry (see following for preparation) to the roots of pine seedlings prior to transplanting. Treat seedlings by dipping roots or use any other suitable means which allows thorough coating. Keep roots moist until transplanted. Prepare the slurry as follows: Add 1.6 ounces (2 ½ tablespoons) of Furadan® 4F to ½ gallon of water. Mix thoroughly. Add 2 pounds of pulverized kaolin clay (pH 4.5) to this suspension. Mix thoroughly. This is sufficient to treat the roots of 150 to 200 seedlings. Adequate ventilation is required for indoor treatment."

Furadan® 4F contains 4 lbs carbofuran per gallon. Thus, each gallon of slurry prepared according to the directions contains 0.1 lbs AI (1.6 ounces product per ½ gallon slurry = 3.2 ounces product per gallon slurry; 3.2 ounces product = 0.025 gallon product; 4 lbs AI/gallon product). Handlers were assumed to wear clothing and PPE listed on product labels.

The M/L exposure estimate is based on data from PHED. Because carbofuran is a Toxicity Category I pesticide, a closed system is required during mixing and loading, unless one gallon or less is handled per day from the original one gallon container (3 CCR 6746). For this scenario, there is no information available on amounts of AI handled daily, although it is possible that thousands of seedlings are treated daily (Beauvais, 2004). For exposure estimates, it was assumed that 40 gallons of solution would be handled daily (sufficient to treat up to 8,000 seedlings); thus a closed-system was assumed for M/L exposure estimates.

As details about pesticide root dipping are lacking, exposure estimates for this scenario are based on the assumption that root dips with pesticides are similar to root dips done to protect roots from desiccation, except that pesticidal root dips require workers to wear clothing and PPE specified on pesticide product labels. Workers are assumed to immerse seedling roots into a container such as a bucket or vat while holding seedlings above roots, and that hands are immersed in the pesticide slurry. Several models were evaluated to determine the best estimates of applicator exposure (Beauvais, 2004).

Applicator dermal exposure was estimated from equations in the Risk Assessment Guidance for Superfund, Part E (RAGS-E). The series of calculations is summarized in Appendix 7. The formula used to estimate dermal exposure requires AI concentration in mg/L units. To convert, 0.1 lbs AI = 45,360 mg AI and 1 gallon = 3.79 L. The AI concentration is about 12,000 mg/L (this concentration is greater than the water solubility of carbofuran; however, the product contains additives to increase AI solubility in water).

Most of the exposure is anticipated to be to hands. However, available information suggests that workers may also be exposed by splashes or drips on the forearms, torso, and legs (Beauvais, 2004). Although this exposure is not immersion in the same way as hands, in the absence of a better approach these exposed body surfaces were also considered in exposure estimates. Dermal exposure via hands and non-hand areas were corrected for 90% protection factors for gloves and clothing (Thongsinthusak *et al.*, 1993a; Aprea *et al.*, 1994). The surface area of both hands was assumed to be 904 cm^2, the value of combined male and female medians; the surface area of the other parts of a worker's body anticipated to be exposed was assumed to be 7,306 cm^2, the total surface area of chest/stomach, forearms, front of thighs and lower legs based on combined male and female medians (U.S. EPA, 1997).

As with dermal exposure, no inhalation exposure monitoring data are available for workers dipping pine seedlings. Inhalation exposure is anticipated to occur, assuming that dipping tanks have a free liquid surface from which chemicals can volatilize into the air. Several models have been proposed to estimate inhalation exposure resulting from volatilization of chemicals from aqueous solutions; three models used by U.S. EPA to estimate exposure to chemicals evaporated from containers or pools of liquid were evaluated in Beauvais (2004). Applicator inhalation exposure was estimated from equations in SWIMODEL (U.S. EPA, 2003), assuming a saturated carbofuran vapor concentration (the vapor concentration calculated by SWIMODEL exceeded this value, and was considered unrealistically high). The calculations are summarized in Appendix 8.

The Acute ADD estimates were 0.002 mg/kg/day for M/L and 1.29 mg/kg/day for applicators (Table 5). Although dip/slurry use on pine seedlings is allowed in California, a review of the 1991 – 2003 PUR shows no reported uses on pine seedlings (DPR, 2005b). Therefore, seasonal, annual and lifetime exposures to carbofuran are not anticipated to occur during activities in these crops, and only acute exposures are estimated.

Reentry Workers

Reentry workers are subject to occupational exposure primarily from contact with dislodgeable carbofuran residues that have accumulated on treated foliage. Potentially significant exposure scenarios for reentry workers were selected based on crop-activity groupings developed by U.S. EPA's Science Advisory Council for Exposure (U.S. EPA, 2000). Scenarios considered to have high exposure potential in U.S. EPA (2000) were assessed. For each of these scenarios, exposure of workers reentering fields following foliar applications of carbofuran was estimated from DFR. Crops on which foliar applications are allowed are listed in Table 1.

In the absence of chemical-specific exposure data for workers entering treated fields, residue decay data and default transfer coefficients (TCs) were used to estimate worker exposure; each TC estimate was based on the crop and the activity of the worker. The absorbed daily dosage (ADD) was calculated as shown in the equation below (Zweig *et al*., 1980; Zweig *et al*., 1985), using a dermal absorption rate (DA) of 50% (Donahue, 1996), a default exposure duration (ED) of 8 hours, and a default body weight (BW) of 70 kg (Thongsinthusak *et al*., 1993a). Acute exposure estimates are given in Table 7.

$$ADD\,(\mu g\,/\,kg\,/\,day) = \frac{DA \times DFR\,(\mu g\,/\,cm^2) \times TC\,(cm^2\,/\,hr.) \times ED\,(hrs.\,/\,day)}{BW\,(kg)}$$

Exposures were estimated for three reentry scenarios. These are considered to be representative scenarios, and protection of workers in these scenarios would be anticipated to protect other reentry workers. Scouting cotton covers all activities in field corn, sweet corn, and sugarcane. Scouting alfalfa covers all activities in alfalfa, barley, wheat, oats, soybeans, and artichokes. Scouting potatoes covers all activities in potatoes.

Reentry workers are not required to wear protective clothing unless entering before expiration of the restricted entry interval (REI). As much reentry work occurs in hot weather and for several hours each day, protective clothing is often not worn by fieldworkers. Therefore, fieldworker exposure estimates were based on an assumption that no protective clothing or equipment was used. Acute exposures were estimated at the expiration of the REI for all activities (Table 7).

Table 7. Acute Exposures to Carbofuran Estimated for Reentry Workers

Exposure scenario	DFR (µg/cm^2) [a]	TC (cm^2/hr) [b]	Acute ADD (mg/kg/day) [c]
Scouting Cotton [d]	0.057	2,000	0.007
Scouting Alfalfa [e]	1.16	1,500	0.099
Scouting Potatoes [f]	0.186	1,500	0.016

[a] Dislodgeable foliar residue (DFR) estimated at expiration of restricted entry interval (REI).
[b] Transfer coefficient (TC) is an estimate of skin contact with treated foliage.
[c] Acute Absorbed Daily Dosage (Acute ADD) calculated as described in text. Assumptions include:
 • Exposure duration = 8 hr
 • Dermal Absorption = 50% (Donahue, 1996)
 • Body weight = 70 kg (Thongsinthusak, *et al*., 1993a)
[d] REI = 14 days for foliar applications. DFR derived from Ware *et al.* (1978). TC from Dong (1990).
[e] REI = 48 hours. DFR derived from Hernandez *et al.* (2002). TC from U.S. EPA (2000).
[e] REI = 48 hours. DFR derived from Barros and Dow (1998). TC from U.S. EPA (2000).

For longer-term exposure estimates it was assumed that workers would not always enter fields at the expiration of the REI. Seasonal, annual and lifetime exposures were estimated at an assumed average reentry of REI + 6 days for cotton scouts and REI + 3 days for alfalfa scouts and potato scouts (Table 8). These assumed averages were not based on data; rather, they were based on the reasonable, health-protective assumption that workers may enter fields an average of 3 - 10 days after expiration of the REI.

Table 8. Exposures to Carbofuran Estimated for Reentry Workers

Exposure scenario	SADD (mg/kg/day) [a]	AADD (mg/kg/day) [b]	LADD (mg/kg/day) [c]
Scouting Cotton [d]	0.0009	0.0001	0.00008
Scouting Alfalfa [e]	0.070	0.012	0.006
Scouting Potatoes [f]	0.010	0.002	0.001

[a] Seasonal Average Daily Dosage is a mean estimate of absorbed dose, calculated as described in text. Dislodgeable foliar residue (DFR) estimates are given below for each scenario.
[b] Annual Average Daily Dosage = ADD x (annual use months per year)/(12 months in a year).
[c] Lifetime Average Daily Dosage = AADD x (40 years of work in a lifetime)/(75 years in a lifetime).
[d] DFR (Day 20) = 0.0076. Estimated seasonal and annual exposure is 2 months.
[e] DFR (Day 5) = 0.819. Estimated seasonal and annual exposure is 2 months.
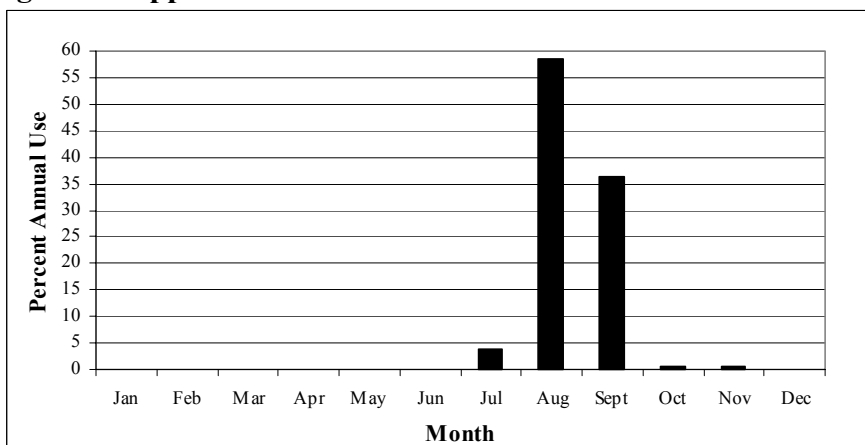[f] DFR (Day 5) = 0.111. Estimated seasonal and annual exposure is 3 months.

Scouting Cotton

Under the Section 18 emergency exemption label, the maximum application rate is 0.5 lb AI/acre (0.56 kg AI/acre), with a limit of two applications per season. The REI is 14 days following foliar application. The DFR value used in exposure estimates was based on a study done in cotton in Arizona (Ware *et al.*, 1978), as discussed in the Environmental Concentrations section. The equation is: $\ln DFR(t) = 1.86 - 0.337t$; $r^2 = 0.92$. From this equation, the DFR on Day 14 was estimated to be 0.057 $\mu g/cm^2$.
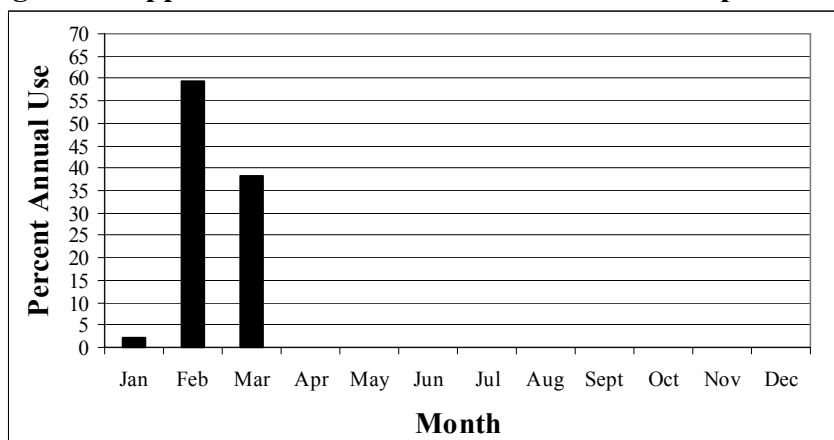
A transfer factor (potential residue transferred to clothing) was derived from a series of studies in which several organophosphates were applied to cotton (Ware *et al.*, 1973, 1974, 1975). Geometric mean transfer factors were computed for bare hands (950 cm^2/hr), the clothed upper body (1,020 cm^2/hr), and the clothed lower body (9,640 cm^2/hr). The transfer factor for the whole body of cotton scouts (11,600 cm^2/hr) was calculated by summing these individual geometric mean transfer factors (Dong, 1990). Assuming a clothing penetration of 10%, the TC used to estimate exposure to cotton scouts was 2000. The Acute ADD for cotton scouts was estimated to be 0.007 mg/kg/day.

Figure 7 shows the relative numbers of cotton acres treated with carbofuran on a monthly basis for the most recent five years for which data are available, 1999-2003 (DPR, 2005b; queried July 28, 2005). In the high-use county of Fresno, most applications occurred in August and September. For seasonal and annual exposure estimates, all applications shown in Figure 7 were assumed to be foliar applications, and it was assumed that scouts were exposed on each workday for these two months. Estimates of seasonal, annual and lifetime exposure are given in Table 8.

Scouting may occur at any time, and was assumed to potentially occur following pesticide use (e.g., to confirm efficacy of the application). Figure 8 summarizes applications of carbofuran to alfalfa in Imperial County, based on acres treated each month for the most recent five years for which data are available, 1999-2003 (DPR, 2005b; queried July 15, 2005). Most carbofuran use on alfalfa during the five-year period occurred in Imperial County. The majority of carbofuran use on alfalfa occurred in February and March (Figure 8). For seasonal and annual exposure estimates, it was assumed that workers were exposed on each workday for these two months. Estimates of seasonal, annual and lifetime exposure are given in Table 8.

Figure 7. Applications of Carbofuran to Cotton in Fresno County, 1999 – 2003 [a]

[a] Percent calculations based on acres of cotton treated (DPR, 2005b; queried July 28, 2005).

Figure 8. Applications of Carbofuran to Alfalfa in Imperial County, 1999 – 2003 [a]

[a] Percent calculations based on acres of alfalfa treated (DPR, 2005b; queried July 21, 2005).

Scouting Potatoes

The maximum application rate allowed on potatoes is 1.0 lb AI/acre (1.1 kg AI/ha), and the REI following carbofuran applications is 48 hours. For exposure estimates, the estimated DFR 2 days post-application was used, based on data from Barros and Dow (1998), as well as a default TC of 1,500 cm^2/hr (U.S. EPA, 2000). The Acute ADD was estimated at 0.016 mg/kg/day (Table 7).

Scouting may occur at any time, and was assumed to potentially occur following pesticide use (e.g., to confirm efficacy of the application). Figure 9 summarizes applications of carbofuran to potatoes in San Joaquin County, based on acres treated each month for the most recent five years for which data are available, 1999-2003 (DPR, 2005b; queried July 15, 2005). Most carbofuran use on potatoes during the five-year period occurred in San Joaquin County. The majority of carbofuran use on potatoes occurred in July through September (Figure 9). For seasonal and annual exposure estimates, it was assumed that workers were exposed on each workday for these three months.   Estimates of seasonal, annual and lifetime exposure are given in Table 8.

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Figure 9. Applications of Carbofuran to Potatoes in San Joaquin County, 1999 – 2003 [a]

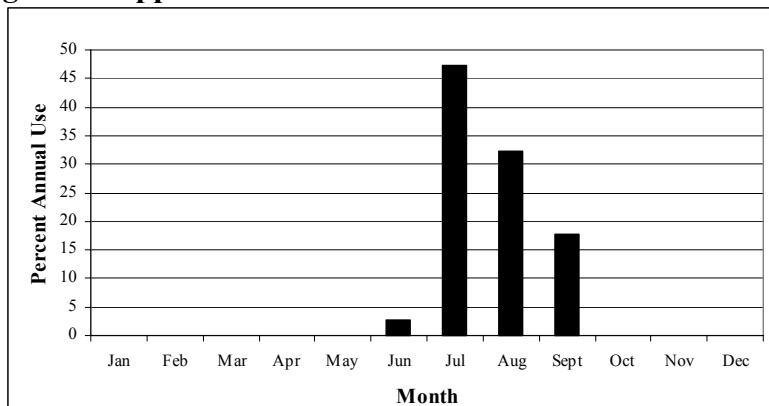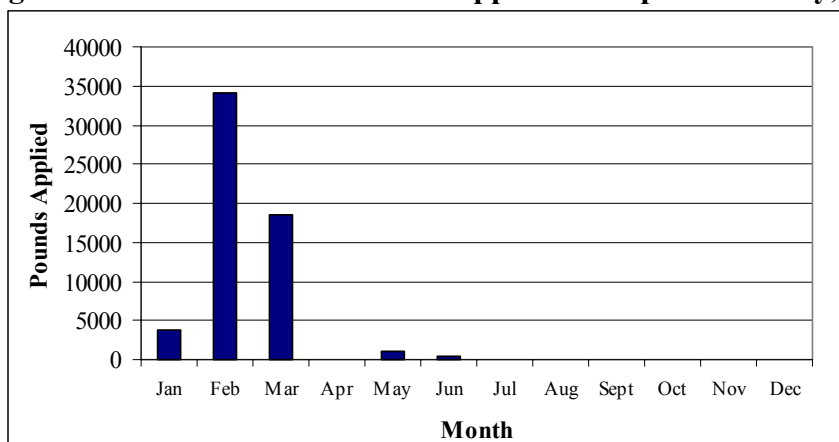[a] Percent calculations based on acres of potatoes treated (DPR, 2005b; queried July 21, 2005).

Ambient Air and Bystander Exposures

Ambient air and application site air monitoring detected carbofuran, suggesting that the public may be exposed to airborne carbofuran. Individuals might be exposed to carbofuran if they live, work, or perform other activities adjacent to fields that are being treated or have recently been treated (bystander exposure). Also, air monitoring studies in Imperial and Sacramento counties suggest that airborne carbofuran exposures are possible in urban areas, and in areas that are far from application sites (ambient air exposure). Ambient air and bystander exposures are perhaps more likely in California than in other parts of the U.S. because of the close proximity of urban and agricultural areas in parts of the state where the greatest carbofuran use occurs (CAST, 2002). Public exposure to airborne carbofuran was estimated, based on monitoring studies of carbofuran at application sites and in ambient air. See the Environmental Concentrations section for study details.

Ambient Air
Carbofuran concentrations in ambient air were higher in Imperial County than in Sacramento County (ARB, 1995; Majewski and Baston, 2002). This coincided with greater use in Imperial County than in Sacramento County (total annual use 58,200 and 2,750 pounds, respectively; see Figures 10 and 11).

Whereas ambient air monitoring was done year-round in Sacramento County (Majewski and Baston, 2002), it was only done for two months in Imperial County (ARB, 1995). Figure 10 shows the use of carbofuran in Imperial County in 1995, the year ambient air sampling was done in Imperial County. Figure 10 shows that the ambient air sampling, which was done in February and March, coincided with the greatest use of carbofuran in Imperial County in 1995. Examination of use in 1999 – 2003 (DPR, 2005b; data not shown) suggested that this pattern is consistent from year to year, and that exposures to carbofuran in ambient air are most likely to occur in February and March. Smaller amounts of carbofuran are used in January, May and June.

Figure 10. Pounds of Carbofuran Applied in Imperial County, 1995 [a]

[a] Based on pounds applied by all methods to all crops in Imperial County (DPR, 2005b; queried December 14, 2005).

In comparison, in Sacramento County during air monitoring in 1996 – 1997 the greatest use occurred in either September or October, with substantial use also occurring in March, May and June (Figure 11). Examination of use in 1999 – 2003 (DPR, 2005b; data not shown) suggested that use in March has increased, while use in other months has decreased, but most the use occurred in one to four months (specific months varied between years). Each year, exposures to carbofuran in ambient air are assumed most likely to occur during the months of greatest use, and exposure estimates were based on an assumption that greatest use will occur in four months each year.

Figure 11. Pounds of Carbofuran Applied in Sacramento County, 1996 and 1997 [a]

[a] Based on pounds applied by all methods to all crops in Sacramento County (DPR, 2005b; queried December 14, 2005).

Table 9 summarizes ambient air exposure estimates to carbofuran based on ambient air monitoring studies in Imperial and Sacramento counties. Following DPR practice, acute ADDs were calculated with 95% percentile concentrations estimated using lognormal methods. DPR's experience with many large environmental datasets has shown that they are usually well described by the lognormal distribution.

Acute ADD for ambient air exposures in Imperial County ranged 0.000004 – 0.000032 mg/kg/day for infants and 0.000002 – 0.000015 mg/kg/day for adults (Table 9). Acute ADD for ambient air exposures in Sacramento County ranged 0.0000010 – 0.0000012 mg/kg/day for infants and 0.0000005 – 0.0000006 mg/kg/day for adults.

Seasonal and annual exposure estimates shown in Table 9 were based on high-use months as shown in Figures 10 and 11. Seasonal and annual exposures were not estimated at sites where carbofuran was not detected (Site H) or detected once (Sites C and EC). Seasonal ADD ranged 0.000004 – 0.000019 mg/kg/day for Imperial County and 0.0000002 – 0.0000005 mg/kg/day for Sacramento County. Annual ADD ranged 0.000001 – 0.000003 mg/kg/day for Imperial County and 0.00000007 – 0.0000002 mg/kg/day for Sacramento County.

Table 9. Exposure Estimates for Persons Exposed to Carbofuran in Ambient Air [a]

Site	Air Concentration [b] ($\mu g/m^3$) Mean	SD	95th Percentile Conc. [c]	Acute ADD [d] (mg/kg/day) Infants	Adults	Seasonal ADD [e] (mg/kg/day) Infants	Adults	Annual ADD [f] (mg/kg/day) Infants	Adults
Imperial County									
Site C [g]	0.007	0.003	0.012	0.000007	0.000003	NA [h]	NA	NA	NA
Site M	0.014	0.008	0.032	0.000019	0.000010	0.000008	0.000004	0.000001	0.000001
Site EC	0.007	0.002	0.010	0.000006	0.000003	NA	NA	NA	NA
Site H [i]	0.006	0.001	0.006	0.000004	0.000002	NA	NA	NA	NA
Site PM	0.033	0.037	0.118	0.000070	0.000034	0.000020	0.000010	0.000003	0.000002
Sacramento County Metro (Downtown)									
South	0.0007	0.0011	0.0024	0.0000014	0.0000007	0.0000004	0.0000002	0.0000001	0.00000007
North	0.0009	0.0020	0.0027	0.0000016	0.0000008	0.0000005	0.0000003	0.0000002	0.0000001

[a] Imperial County data from ARB (1995). Sacramento County data from Majewski and Baston (2002). The total number of observations in Imperial County data sets, including non-detects, was 14 except for site PM, which had 12; the total numbers of observations in the Sacramento County Metro site were 66 for south winds and 50 for north winds. Appendix 1 summarizes ambient air monitoring data on which exposure estimates are based.
[b] Calculated using ½ detection limit (reporting limit) for non-detects.
[c] Concentration (in $\mu g/m^3$) used for acute exposure estimates. Calculated using lognormal distribution methods.
[d] Acute Absorbed Daily Dosage ($\mu g/kg/day$) = (95th percentile upper bound air concentration) x (inhalation rate). Calculation assumptions include:
 • Infant inhalation rate = 0.59 $m^3/kg/day$ (Layton, 1993; U.S. EPA, 1997)
 • Adult inhalation rate = 0.28 $m^3/kg/day$ (Wiley *et al*., 1991; U.S. EPA, 1997; OEHHA, 2000)
 • Inhalation absorption is assumed to be 100%
[e] Seasonal ADD = (mean air concentration) x (inhalation rate). Calculation assumptions as above.
[f] Annual ADD = (Seasonal ADD) x (number of high-use months/12). Imperial County: two high-use months. Sacramento County: four high-use months.
[g] Site C: Calipatria. Site M: Meadows Union School. Site H: Heber. Site EC: El Centro. Site PM: Air Pollution Control District monitoring station.
[h] NA: Not applicable. Seasonal and annual exposure estimates not done at sites with no detects or one detect (i.e., Site C, Site EC, and Site H).
[i] All samples at this site were non-detects. Calculated concentrations varied slightly due to different sample volumes.

Bystanders at Application Sites

To estimate bystander exposure to carbofuran in air, data were used from application site monitoring in a 1993 study in Imperial County (ARB, 1994). Stations (one each east, west and south, and two north) were located 20 m from the edge of the field. The application took place on March 31 between 10:00 and 11:00 AM. Table 4 summarizes air concentrations during several monitoring periods at each of these stations.

Table 10 summarizes the bystander exposure estimates. As available information suggests that exposures of less than 24 hours can result in toxicity, 1-hour exposure estimates were calculated based on the highest measured concentration during a one-hour measuring period. This maximum concentration measured by ARB occurred during the first hour of monitoring during the application at the east monitoring station (0.66 µg/m^3). However, in ARB (1994) carbofuran was applied at a rate (0.3 lb AI/acre) that was below the maximum application rate allowed on alfalfa (1.0 lb AI/acre). Bystanders near a field receiving the maximum application rate would be anticipated to be exposed to higher concentrations than measured by ARB (1994). The concentration used to estimate exposure was therefore adjusted (multiplied by 1.0/0.3 = 3.3) to 2.2 µg/m^3. The 1-hour absorbed dose was 0.000550 mg/kg/hr for infants and 0.000099 mg/kg/hr for adults.

Table 10. Bystander Exposure Estimates for Carbofuran [a]

	Adjusted Carbofuran Concentration (µg/m^3) [b]	Inhalation Rate [c]	Absorbed Dose [d]
1-Hour Absorbed Dose (during heavy activity for 1 hour) [e]			
Infant	2.2	0.16 m^3/kg/hr	0.000550 mg/kg/hr
Adult	2.2	0.022 m^3/kg/hr	0.000099 mg/kg/hr
Acute Absorbed Daily Dosage (Acute ADD) [f]			
Infant	0.77	0.59 m^3/kg/day	0.000454 mg/kg/day
Adult	0.77	0.28 m^3/kg/day	0.000216 mg/kg/day

[a] Based on air monitoring done 20 m from an Imperial County alfalfa field in 1993 (ARB, 1994).

[b] Carbofuran concentrations were multiplied by the ratio of maximum allowed application rate on alfalfa (1.0 lb AI/acre) to the 0.3 lb AI/acre rate used by ARB (1994), to get adjusted concentrations for exposure estimates.

[c] Different inhalation rates were used for the 1-hour and acute 24-hour absorbed doses. The inhalation rates for 1-hour absorbed dose estimates were calculated from values reported in Andrews and Patterson (2000), assuming heavy activity and dividing by the mean body weight for males and females (71.8 kg). Hourly inhalation rates for heavy activity are 1.9 m^3/hr for infants (Layton, 1993; U.S. EPA, 1997) and 3.2 m^3/hr for adults (Wiley *et al.*, 1991; U.S. EPA, 1997; OEHHA, 2000). Daily inhalation rates are default values from Andrews and Patterson (2000).

[d] 1-hour absorbed doses assume 1-hour exposure during heavy activity, and are based on highest carbofuran concentration measured by ARB (1994). Absorbed daily doses assume a typical mixture of activity levels throughout the day and are based on the highest 24-hour time-weighted average (TWA) air concentrations from ARB (1994).

[e] 1-hour absorbed dose (mg/kg/hr) = (highest 1-hour air concentration) x (inhalation rate). The maximum 1-hour concentration from Table 4 (0.66 µg/m^3), from the East air monitoring station, was adjusted as described in Footnote [b].

[f] Acute ADD (mg/kg/day) = (TWA air concentration) x (inhalation rate). The 24-hour TWA concentration from Table 4 (TWA = 0.23 µg/m^3), from the West air monitoring station, was adjusted as described in Footnote [b].

The 24-hour time-weighted average (TWA) for the west monitoring station (TWA = 0.23 µg/m^3) was used to estimate daily exposure. This concentration was adjusted for the sub-maximum application rate used in the application monitored in ARB (1994), to 0.77 µg/m^3. Acute ADD for bystanders was 0.000454 mg/kg/day for infants and 0.000216 mg/kg/day for adults. Seasonal or annual exposure to application site airborne carbofuran levels is not expected because airborne concentrations are anticipated to reach ambient levels within a few days after the application, and seasonal and ambient air carbofuran exposure estimates are given in Table 9.

EXPOSURE APPRAISAL

Handler Exposure Estimates

PHED

Exposure estimates for handlers were based on surrogate data, due to lack of acceptable, chemical-specific data. Data from PHED were used to estimate handler exposures for the various application methods, with the exception of nursery stock dipping applicators. PHED, though useful, has limitations that prevent the use of distributional statistics on exposure estimates. For example, PHED incorporates exposure data from many studies, each with a different minimum detection level for the analytical method used to detect residues in the sampling media. Moreover, as the detection of dermal exposure to the body regions was not standardized, some studies observed exposure to only selected body parts. Consequently, the subsets derived from the database for dermal exposure may have different numbers of observations for each body part, a fact which complicates interpretation of values taken from PHED. However, use of PHED data provided the best exposure estimates possible.

The mean estimates provided by PHED for groundboom applicators were lower than results of exposure monitoring of applicators and M/L/A reported by Hussain *et al.* (1990). The arithmetic mean total exposure rate reported by Hussain *et al.* (1990) was 574.4 µg AI/lb handled. The six handlers (two applicators and four M/L/As) monitored by Hussain *et al.* (1990) had the following six total exposure estimates: 33.8, 42.6, 123.6, 223.6, 437.2, and 2,585.6 µg AI/lb handled. Note that five of the six handlers monitored by Hussain *et al.* (1990) had exposures below the arithmetic mean (574.4 µg AI/lb), a result that is fairly typical in exposure monitoring data sets. For comparison, the geometric of exposure results is also provided in Table 11. Three of the six handlers monitored by Hussain *et al.* (1990) had exposures below the geometric mean (188.6 µg AI/lb), while three handlers had exposures greater than the geometric mean; again, this result is fairly typical for exposure monitoring data sets.

To calculate PHED-based estimates of M/L/A exposure in Table 11, M/L and applicator exposure estimates were combined based on an assumption that during an 8-hour workday, 2 hours would be spent mixing/loading and 6 hours applying (actual mixing/loading and application times were not reported by Hussain *et al.* (1990), and may have differed from this assumption). PHED-based estimates are shown in Table 11 assuming conditions as in the study, and conditions that conform with California requirements. The exposure estimate that assumed

study conditions was nearly four times as great as the estimate assuming conditions that meet California requirements; however, it was only slightly greater than the geometric mean of exposures reported by Hussain *et al.* (1990).

In Table 5 in the Exposure Assessment section, the PHED mean estimates used in calculating Acute ADD for groundboom mixer/loaders and applicators are 77.8 and 107 μg/lb handled, respectively. If the two lowest results reported by Hussain *et al.* (1990) are for the two applicators, then PHED overestimated the applicator exposure by about three-fold (107 μg AI/lb handled vs. 33.8 and 42.6 μg AI/lb handled). However, insufficient information was provided by Hussain *et al.* (1990) to assign exposure results to handler activities in that study.

Table 11. Comparison of Groundboom Mixer/Loader/Applicator Exposure to Carbofuran Estimated from Surrogate Data by DPR with Chemical-Specific Exposure Monitoring

Exposure estimate	Exposure rate (μg AI/lb handled) [a]	STADD (mg/kg/day) [b]
From PHED, DPR policy, California and label requirements [c]	51.6	0.147
From PHED, according to DPR policy, study conditions [d]	201	0.573
From study, arithmetic mean of exposure data [e]	574.4	1.64
From study, geometric mean of exposure data [e]	188.6	0.539

[a] Total exposure rate, dermal plus inhalation. Estimates based on the Pesticide Handlers Exposure Database (PHED) were calculated by adding together exposure of mixer/loader (M/L) plus applicator, assuming 2 hours M/L and 6 hours application (i.e., ¼ and ¾ daily exposure estimates, respectively).

[b] Short-Term Absorbed Daily Dosage (STADD) estimates assumed a maximum application rate of 10 lbs AI/acre, maximum rate on field-grown ornamentals, and an 8-hour workday. Amount treated was assumed to be 40 acres treated/day (Haskell, 1998). Dermal absorption assumed to be 50% (Donahue, 1996), inhalation absorption assumed to be 100%, and body weight assumed to be 70 kg (Thongsinthusak *et al.*, 1993a).

[c] Exposure rate estimates incorporated assumptions used in the Department of Pesticide Regulation (DPR) Exposure Assessment. For M/L, use of a closed system was assumed, and applicators were assumed to have open-cab tractors. Workers were assumed to wear long-sleeved shirt and long pants, gloves and respirator.

[d] PHED-based estimates prepared according to assumptions listed above, except for clothing and protective equipment open-pour mixing/loading. Applicators assumed to wear respirator and coveralls over long-sleeved shirt and long pants, but not wearing gloves; mixing/loading was open-pour and M/L assumed to wear coveralls over long-sleeved shirt and long pants, and chemical-resistant gloves and respirator.

[e] Hussain *et al.* (1990), based on passive dosimetry (patches beneath work clothing, hand rinses, personal air samplers). Total exposure estimates: 33.8, 42.6, 123.6, 223.6, 437.2, and 2,585.6 μg AI/lb handled. Four individuals were mixer/loader/applicators and two were applicators; however, the workers doing only application were not identified.

U.S. EPA also used PHED to estimate handler exposure (Weiss, 2005); however, U.S. EPA approaches PHED data somewhat differently than DPR. First, as explained in U.S. EPA's policy for use of PHED data (U.S. EPA, 1999): "Once the data for a given exposure scenario have been selected, the data are normalized (i.e., divided by) by the amount of pesticide handled resulting in standard unit exposures (milligrams of exposure per pound of active ingredient handled). Following normalization, the data are statistically summarized. The distribution of exposure values for each body part (i.e., chest upper arm) is categorized as normal, lognormal, or "other" (i.e., neither normal nor lognormal). A central tendency value is then selected from the

distribution of the exposure values for each body part. These values are the arithmetic mean for normal distributions, the geometric mean for lognormal distributions, and the median for all "other" distributions. Once selected, the central tendency values for each body part are composited into a "best fit" exposure value representing the entire body." In other words, U.S. EPA uses various central tendency estimates (often the geometric mean or median, as PHED data rarely follow a normal distribution), while DPR believes the arithmetic mean is the appropriate statistic regardless of the sample distribution (Powell, 2003). Second, for acute exposure estimates DPR uses a 95th percentile upper bound estimate, while U.S. EPA uses a central tendency estimate for all exposure durations (U.S. EPA, 1998b). Third, as explained in the Exposure Assessment section, DPR calculates upper 90% confidence limits for both upper bound and mean exposures, while U.S. EPA does not (note: DPR's policies for handling PHED data have been reviewed informally and are currently under formal review by a statistician at the University of California).

The acute exposure estimates from DPR (Table 5) and short-term exposure estimates for U.S. EPA (Weiss, 2005) are summarized in Table 12 for several scenarios. U.S. EPA did not provide separate long-term handler exposure estimates.

Table 12. Comparison of Estimated Short-Term Exposures to Carbofuran for Selected Handler Scenarios by DPR and U.S. EPA [a]

Scenario	DPR Exposure Rate (µg/lb AI handled)		DPR Exposure (mg/kg/day)	U.S. EPA Exposure Rate (µg/lb AI)		U.S. EPA Exposure (mg/kg/day)
	Dermal	Inhalation		Dermal	Inhalation	
Aerial M/L [b]	77.3	0.512	0.560	8.6	0.083	0.0102
Groundboom M/L [c]	77.3	0.512	0.224	8.6	0.083	0.00337
Aerial App [d]	891	2.86	6.40	5.0	0.068	0.0063
Groundboom App [e]	102	4.72	0.318	14	0.15	0.00566
LPHW M/L/A [f]	9,480	137	0.002	430	6	0.0000113

[a] Department of Pesticide Regulation (DPR) estimates reported in Table 5 of this document. U.S. Environmental Protection Agency (U.S. EPA) estimates reported in Appendix A of Weiss (2005) for conditions identical to those assumed in DPR estimates, unless otherwise stated. U.S. EPA did not provide separate long-term handler exposure estimates.
[b] Mixer/loader (M/L) using a closed system in support of aerial applications to alfalfa.
[c] M/L using a closed system in support of groundboom applications to ornamentals.
[d] Aerial applicator, alfalfa. DPR assumed open cockpit, while U.S. EPA provided estimates only for a closed cockpit.
[e] Groundboom applicator, ornamentals. Estimates assumed open cockpit.
[f] Mixerl/loader/applicator (M/L/A) applying carbofuran as a soil drench using a low pressure handwand (LPHW). Open-pour mixing/loading assumed.

Acute handler exposure estimates shown in Table 12 range from 0.002 – 6.40 mg/kg/day for DPR and from 0.0000113 - 0.0102 mg/kg/day for U.S. EPA. DPR exposure estimates shown in Table 12 are from 55 to 176 times larger than exposure estimates from U.S. EPA when conditions are assumed to be the same. There are several factors contributing to these differences, including dermal absorption (50% assumed by DPR versus 6% assumed by U.S. EPA, an eight-fold difference) and the use of an upper-bound estimates by DPR while U.S. EPA used central tendency estimates for exposure estimates reported by Weiss (2005).

The aerial applicator estimate for DPR is 888 times as great as the estimate for U.S. EPA. These values differ substantially, not only for the reasons explained above, but also because U.S. EPA assumes use of closed cockpits in all aerial exposure estimates; if planes with open cockpits can be used, U.S. EPA policy is to require an additional 10-fold safety factor in the risk calculation (U.S. EPA, 1998c). If DPR were to assume a closed cockpit, the total exposure rate would be 46.7 μg AI/lb handled, and the total exposure would be 0.667 mg/kg/day; this estimate is 106 times the estimate provided by U.S. EPA for this scenario. This comparison shows the extent to which assumption of an open cockpit affects DPR exposure estimates (nearly a ten-fold difference). The most recent information available about equipment used by aerial applicators shows that open cockpits are relatively rare, but may still be used (NAAA, 2004).

Dip/Slurry Applicators

Dermal exposure was estimated based on the RAGS-E model, which estimates skin permeability (K_p) to organic chemicals in aqueous solution (U.S. EPA, 2004a). There are many assumptions and uncertainties with this and other models that use K_p, many of which were discussed in U.S. EPA (2004a). Additional sources of uncertainty in models based on large and diverse data sets were discussed by Poda *et al.* (2001).

For carbofuran, an AI-specific K_p value was estimated based on an equation derived from a data set of about 200 diverse organic compounds in aqueous solutions. The calculated K_p for carbofuran may be either over- or underestimated; there are not enough data available to be sure. The diversity of chemicals in the data set on which the K_p equation is based decreases confidence in estimates based on the equation (Poda *et al.*, 2001). As carbofuran is well within the range of MW and Log K_{ow} in which K_p estimates are considered valid, based on Equations 3.9 and 3.10 in U.S. EPA (2004a), use of this equation is expected to result in a skin permeability estimate that correlates reasonably well with available data.

However, use of K_p with solutions of formulated pesticide products may result in exposure being underestimated, as the formulations contain additives (e.g., solvents, emulsifiers, and surfactants) to increase water solubility of AIs. Numerous studies have shown enhanced dermal penetration of chemicals, including pesticides, when mixed with such additives, as they can alter the barrier properties of the skin (Baynes and Riviere, 1998; Nielsen *et al.*, 2000; Brand and Mueller, 2002; Williams and Barry, 2004). Alternately, flux could be decreased by additives in the formulation, as has been shown in some cases (Nielsen and Andersen, 2001; Riviere et al., 2001), perhaps by altering how the chemical partitions between solution and skin (van der Merwe and Riviere, 2005). Exposure estimates could be improved if skin permeability measures were made using solutions of formulated products in concentrations that are pertinent to typical product use. Because carbofuran is used in a clay slurry rather than an aqueous solution, some of the AI may be anticipated to partition to clay particles and not be available for exposure, resulting in lower exposures than estimated (U.S. EPA, 2004a).

Another uncertainty from the use of K_p in estimating dermal exposure is that skin permeabilities are almost always estimated from *in vitro* rather than *in vivo* data. In an *in vitro* skin permeability test, a section of skin is clamped between two cells, called the "donor cell" and the "receptor cell." The donor solution (in the donor cell) contains the compound of interest; as the

compound passes through the skin section it appears in the receptor solution, which is sampled periodically. A known concentration of compound is initially in the donor solution; the rate at which the compound concentration in the receptor solution increases is related to the permeability. The use of *in vitro* data introduces uncertainties because relationships between *in vivo* and *in vitro* test results have not been reliably established for many classes of compounds, and have been shown to vary for compounds that have been tested (Wester and Maibach, 2000; Zendzian and Dellarco, 2003). Nevertheless, these models rely on the assumption that *in vitro* dermal penetration is approximately the same as *in vivo*.

Other assumptions common to these models are that the chemical concentration of water in contact with skin (C_w) is constant; and that absorbed dose is a function of solution concentration, skin permeability, and amount of exposed skin surface. These are reasonable assumptions, but have not been tested for solutions of pesticide products.

Additional uncertainty exists in the RAGS-E model, in the parameters τ and B. Calculations for these parameters rely on many assumptions and limited, surrogate data. The RAGS-E model has undergone some validation, but not with carbofuran in formulated products (additives in the pesticide formulations may affect τ and B, as well as K_p).

Inhalation exposure for workers dipping pine seedling roots was estimated based on SWIMODEL equations. SWIMODEL estimates pesticides concentrations in air based on conditions that may not be met in the root dipping scenario. In fact, substantial deviations occur from the assumptions on which the model is based. SWIMODEL relies on water-air partitioning to determine concentration of a chemical in air, using the Henry's Law constant for the chemical. However, Henry's Law constant applies to dilute, single-chemical aqueous solutions only. Staudinger and Roberts (2001) give 10,000 mg/L as an upper boundary defining a "dilute" solution under Henry's Law. This concentration is exceeded in the carbofuran slurry (12,000 mg/L). Furthermore, other chemicals present in the pesticide formulation (as well as the clay mixed into the slurry) can interact with the pesticide molecules, potentially affecting the partitioning of the AI into air (Staudinger and Roberts, 2001). Because the calculated concentration of AI in air was higher than anticipated at saturation, the estimated saturation concentration was used instead in inhalation exposure calculations; in other words, it was assumed that the AI is present at air-saturating concentrations. Because of this assumption, inhalation exposure is anticipated to be overestimated. In spite of this, the inhalation exposure estimate was substantially below the dermal exposure estimate, and the inhalation contribution to total exposure is considered negligible in this scenario.

In the absence of exposure monitoring or surrogate data, the results obtained from these models are considered the best estimate of dermal and inhalation exposure based on available information.

Other Defaults
Most exposure estimates reported in this EAD assumed a median body weight of 70 kg (Thongsinthusak, 1998). Bystander estimates assumed a mean body weight of 71.8 kg, for consistency with the mean inhalation rates that are used in the calculation (Andrews and Patterson, 2001). Both of these might be underestimates, based on trends in body weights in

U.S. populations in general, in which mean weights of adults over age 21 increased between the two most recent intervals (Ogden *et al*., 2004). As exposure estimates are divided by assumed body weight, underestimates in body weight might result in overestimated exposure.

PUR data were used to estimate likely numbers of days workers were exposed, based on the distribution of applications in high-use California counties. These high-use periods describe a recent work history of the handler population, and they probably overestimate the workdays for any single individual. They provide the best available data for long-term exposure estimates, however.

PUR data could perhaps be used more extensively in estimating long-term exposure, by providing central tendency estimates of lbs AI/acre and acres treated; DPR is currently considering such a change. In this EAD, for both short-term and long-term exposure estimates, maximum allowed application rates were used, from product labels. The numbers of acres treated per day were based on defaults recommended by U.S. EPA (2001), with the exception of groundboom applications, which used an estimate provided by a county Deputy Agricultural Commissioner. These estimates are expected to be conservative but realistic; however, insufficient data exist to evaluate their accuracy.

Reentry Worker Exposure Estimates

Acceptable monitoring data were lacking for reentry worker exposures. Exposure estimates for reentry workers were based on chemical-specific, crop-specific DFR values. Two scenarios, scouting cotton and scouting alfalfa, are representative scenarios that cover activities in other crops. Residues may dissipate at different rates on different crops, due to factors such as leaf topography and physical and chemical properties of leaf surfaces, and exposures of workers in other crops might therefore vary from estimates.

Extent of foliage contact, unlike DFR, is not chemical specific, and TC values for various crop activities are readily available, based on studies using other chemicals. Where crop-specific TC were not available, general defaults were used. These defaults were likely to be health-protective (U.S. EPA, 2000).

Additionally, information is lacking about exposures resulting from some activities, such as weeding and roguing (removal of diseased crop plants) in cotton, and how these exposures might compare with those of scouts. And unlike most other reentry workers, cotton harvesters are working in plants which have been intentionally defoliated; DFR residues therefore cannot be used to estimate harvester exposures. The best available exposure estimate for weeders, roguers and harvesters in cotton is considered to be the estimate provided for cotton scouts. However, no data are available which would allow comparison of exposures between cotton scouts and those of other reentry workers in cotton.

Unlike handler exposure estimates, reentry exposures estimated by DPR and U.S. EPA did not differ substantially. For example, the exposure estimate for scouting potatoes in Table 7 of the Exposure Assessment section was slightly less than 9-fold greater than the estimate for that scenario in Appendix B of Weiss (2005). Most of that difference can be attributed to the eight-

fold difference in dermal absorption estimates (50% assumed by DPR versus 6% assumed by U.S. EPA). There were slight differences in DFR estimates.

In general, foliar residues are assumed to result from foliar applications, and this assumption was followed in worker exposures estimated in this document. That is, the only exposure scenarios considered to be potentially significant involved reentry following foliar, rather than soil applications. For example, reentry activities in grapes were considered to result in insignificant exposures, as only soil applications are allowed in grapes. However, carbofuran has been shown to be readily translocated to leaves in some plants following applications to soil (Arunachalam and Lakshmanan, 1982; Buyanovsky *et al*., 1995). Whether translocated carbofuran might be available as dislodgeable residues has apparently not been investigated. Even if residues were available for transfer to reentry workers, however, they are not likely to result in significant exposures.

Ambient Air and Bystander Exposure Estimates

Public exposures to airborne carbofuran were estimated based on concentrations of carbofuran in air and assumptions about uptake of carbofuran from the air. No biomonitoring or other exposure monitoring data were available. Exposure estimates were provided for adults for consistency with other scenarios, and for infants, as likely worst-case because infants have the greatest inhalation rate per body weight.

Ambient air exposure estimates were provided for five sites in Imperial County and for downtown Sacramento. Exposure estimates in Sacramento were approximately an order of magnitude lower than in Imperial County. Even in Imperial County, there were a number of samples in which carbofuran was not detected. Although ambient air monitoring sites were selected based on anticipated nearby carbofuran use, applications of carbofuran were not confirmed. It is possible that no applications occurred near the sites where carbofuran was not detected. The carbofuran concentrations used to estimate ambient air exposures are based on limited monitoring data and must be considered as having some degree of uncertainty. The representativeness of the sites monitored by ARB (1995) and Majewski and Baston (2002) is unknown. ARB (1995) monitored each site 4 days per week for a relatively short (4-week) period. Weekend days were not monitored. It is unknown whether weekdays and weekends differ systematically in numbers of carbofuran applications.

ARB (1995) reported results for samples above the LOD, rather than the LOQ (in fact, no LOQ was reported). If the LOQ were calculated as the usual 3 x LOD, then ½ LOQ would be substituted for all results below the LOQ. In this EAD, however, DPR followed the same approach as ARB (1995), substituting ½ LOD for results below the LOD; this was done to prevent exposures from being grossly overestimated. DPR believes this is the appropriate approach for these data, although it could result in some exposures being slightly underestimated. Nevertheless, this approach results in a higher exposure estimate for the site with the highest carbofuran concentrations, Site PM. As shown in Table 1-1 in Appendix 1, the 95th percentile concentration at Site PM would be decreased to 0.102 μg/m^3 if results were reported based on an LOQ calculated as 3 x LOD (in contrast, the 95th percentile concentration used to estimate acute exposure at this site is 0.118 μg/m^3; see Table 9). Acute ADD for infants

is 0.000070 mg/kg/day (Table 9); a concentration of 0.102 μg/m^3 would result in the Acute ADD for infants being 0.000060 mg/kg/day.

For bystander exposure estimates, data from the west monitoring station, 20 m from the application site, were used as a reasonable worst-case estimate for carbofuran concentration in air for Acute ADD estimates. For this reason, the mean carbofuran concentration at this site was used rather than the 95th-percentile upper bound estimate. However, this mean concentration was based on monitoring during an application to an alfalfa field where the application rate (0.3 lb AI/acre) was below the maximum allowed on alfalfa (1.0 lb AI/acre). Because of this, the mean concentration was adjusted, using an assumption that concentration would increase proportionately with application rate. This is a reasonable, though untested, assumption. In addition to application rate, bystander exposure may also be underestimated if other factors such as application method result in higher carbofuran concentrations near the application site than concentrations found by ARB (1994). For example, studies done with other pesticides comparing aerial and ground applications have found that drift is greater with aerial than ground application methods (Frost and Ware, 1970; MacCollom *et al.*, 1986). Finally, seasonal or annual exposure to application site airborne carbofuran levels is not expected because airborne concentrations are anticipated to reach ambient levels within a few days after the application.

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APPENDICES

Appendix 1: Carbofuran Concentrations in Ambient Air Monitoring

Table 1-1: Carbofuran Concentrations in Ambient Air Monitoring in Imperial County [a]

Date	Site C [b]			Site M	Site EC	Site H	Site PM
	C1 [c]	C2 [c]	Mean				
February 14, 1995	0.031	*0.006*	0.019	0.023	*0.006*	*0.006*	*0.004*
February 15, 1995	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	NS [d]
February 16, 1995	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	NS
February 21, 1995	*0.007*	*0.007*	*0.007*	0.027	*0.006*	*0.006*	**0.084** [e]
February 22, 1995	*0.006*	*0.006*	*0.007*	0.014	*0.007*	*0.007*	**0.081**
February 23, 1995	*0.006*	*0.006*	*0.006*	0.017	0.014	*0.006*	**0.110**
February 27, 1995	*0.007*	*0.007*	*0.007*	0.017	*0.006*	*0.006*	0.028
February 28, 1995	*0.006*	*0.006*	*0.006*	0.017	*0.006*	*0.006*	0.018
March 1, 1995	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*
March 2, 1995	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	*0.006*	0.017
March 6, 1995	*0.007*	*0.007*	*0.007*	*0.007*	*0.007*	*0.006*	*0.006*
March 7, 1995	*0.007*	*0.007*	*0.007*	*0.007*	*0.007*	*0.007*	*0.007*
March 8, 1995	*0.007*	*0.007*	*0.007*	0.027	*0.006*	*0.008*	0.017
March 9, 1995	*0.007*	*0.007*	*0.007*	0.018	*0.006*	*0.006*	0.019
Mean [f]	0.008	0.006	0.007	0.014	0.007	0.006	0.033
SD [f]	0.007	0.0003	0.003	0.008	0.002	0.0006	0.037

[a] Monitoring at sites in Imperial County (ARB, 1995). Concentrations are reported in $\mu g/m^3$. For results below the limit of detection (LOD), ½ of the LOD was reported; these values are italicized. The LOD for each sample was dependent on the volume of air sampled. The analytical LOD was 0.25 μg/ml sample (about 0.012 $\mu g/m^3$ for a 24-hour sample).
[b] Site C: Calipatria Fire Department, duplicate samplers. Site M: Meadows Union School, Holtville. Site EC: El Centro Air Pollution Control District (APCD) Office (urban background site). Site H: Felipe and Ramon School, Heber. Site PM: APCD PM-10 Monitoring Station, Brawley.
[c] Results from duplicate samplers labeled C1 and C2. Means of each pair of samples used to calculate overall mean, which was used in estimating exposure.
[d] NS: No sample on this date, due to instrument malfunction.
[e] Concentrations in bold are above the limit of quantification (LOQ), calculated for this exposure assessment as the usual 3 x LOD (ARB (1995) did not report an LOQ). The calculated LOQ was 0.75 μg/ml sample (about 0.036 $\mu g/m^3$ for a 24-hour sample). If concentrations at Site PM were reported above the LOQ rather than the LOD, with ½ LOQ used for values below the LOQ, the mean $\pm$ standard deviation concentration at this site would be 0.036 $\mu g/m^3 \pm$ 0.034 $\mu g/m^3$, and the 95th percentile concentration for Site PM would be 0.102 $\mu g/m^3$. That is, the mean concentration would be slightly greater than and the 95th percentile concentration would be slightly less than the concentrations used to estimate exposure to carbofuran at this site (the 95th percentile concentration used to estimate acute exposure at this site is 0.118 $\mu g/m^3$; see Table 9).
[f] Arithmetic mean and standard deviation (SD).

Appendix 1, Continued...

Table 1-2: Carbofuran Concentrations in Ambient Air Monitoring in Sacramento County [a]

Date	Carbofuran South [b]	Carbofuran North [b]	Date	Carbofuran South	Carbofuran North	Date	Carbofuran South	Carbofuran North
Jan 2, 1996	*0.000069*	NS [c]	Jul 15, 1996	*0.000078*	*0.00026*	Apr 7, 1997	0.00242	0.00255
Jan 9, 1996	*0.000070*	NS	Aug 12, 1996	*0.000056*	NS	Apr 14, 1997	0.00367	NS
Jan 16, 1996	*0.000074*	NS	Sep 3, 1996	*0.00015*	NS	Apr 21, 1997	0.00194	0.00044
Jan 22, 1996	*0.000072*	NS	Sep 23, 1996	*0.000082*	NS	Apr 28, 1997	*0.000087*	*0.000351*
Jan 29, 1996	*0.000071*	NS	Oct 15, 1996	*0.000275*	*0.00011*	May 5, 1997	0.00183	*0.000631*
Feb 5, 1996	*0.00017*	NS	Nov 4, 1996	*0.000084*	*0.000119*	May 12, 1997	0.00206	*0.000214*
Feb 13, 1996	*0.000082*	NS	Nov 19, 1996	*0.000115*	*0.000148*	May 20, 1997	0.00134	*0.000548*
Feb 20, 1996	*0.000077*	NS	Dec 2, 1996	*0.000062*	*0.000568*	May 27, 1997	0.00309	0.00032
Feb 27, 1996	*0.000072*	NS	Dec 16, 1996	*0.000074*	*0.0010*	Jun 2, 1997	0.00050	0.00351
Mar 4, 1996	*0.00011*	*0.00020*	Dec 30, 1996	*0.000434*	*0.000164*	Jun 10, 1997	0.00099	0.013
Mar 11, 1996	NS	*0.000011*	Jan 7, 1997	*0.000334*	*0.000131*	Jun 16, 1997	0.00099	*0.000179*
Mar 18, 1996	*0.000086*	NS	Jan 13, 1997	*0.000129*	*0.000116*	Jun 23, 1997	0.00008	*0.000301*
Mar 25, 1996	*0.000080*	NS	Jan 21, 1997	*0.000082*	*0.000226*	Jul 7, 1997	0.00046	*0.000531*
Apr 1, 1996	*0.000221*	*0.00021*	Jan 28, 1997	*0.000245*	*0.000228*	Aug 4, 1997	0.00067	*0.000393*
Apr 8, 1996	*0.000095*	NS	Feb 3, 1997	*0.000337*	0.00017	Aug 18, 1997	0.00071	0.00017
Apr 15, 1996	*0.000080*	*0.00041*	Feb 10, 1997	0.000169	0.00093	Sep 2, 1997	0.00016	*0.000598*
Apr 22, 1996	*0.00016*	*0.000071*	Feb 18, 1997	*0.000217*	0.00118	Sep 15, 1997	*0.000187*	0.00094
Apr 29, 1996	NS	*0.00016*	Feb 24, 1997	0.00149	*0.000101*	Sep 29, 1997	0.00031	*0.000211*
May 6, 1996	*0.000068*	*0.00048*	Mar 3, 1997	*0.000622*	*0.000111*	Oct 13, 1997	0.00065	*0.000527*
May 13, 1996	*0.000058*	*0.00062*	Mar 10, 1997	0.00574	*0.000184*	Nov 10, 1997	*0.000105*	NS
May 20, 1996	*0.000058*	*0.000074*	Mar 17, 1997	0.00447	0.00472	Nov 24, 1997	0.000179	0.00091
Jun 10, 1996	*0.000043*	NS	Mar 24, 1997	0.00199	0.00245	Dec 22, 1997	*0.000856*	0.000078
June 24, 1996	*0.000091*	*0.00058*	Mar 31, 1997	*0.000252*	0.00231			
						Mean [d]	0.00069	0.00092
						SD [d]	0.00112	0.00198

[a] Monitoring at the "downtown metro" site in Sacramento County (Majewski and Baston, 2002); the other two sites had just a single detect each. Each sample was collected over a one-week interval. Concentrations are reported in $\mu g/m^3$. For results below the detection limit, ½ of the detection limit was reported; these values are italicized. The detection limit was 0.00015 $\mu g/m^3$ for a 100-m^3 sample.

[b] Results from samplers with directional wind sensors. Sampling was triggered when 15-min mean wind speeds were >1 m/sec in a southerly or northerly direction, and continued until the directional wind speed decreased below the trigger velocity; maximum sampling was 20 min/hr.

[c] NS: No sample, due to low sample volume (e.g., due to low wind conditions during the sample period) or instrument malfunction. Samples were collected over one-week intervals; dates in which no sufficient samples were collected from either north- or south-wind samplers have been omitted.

[d] Arithmetic mean and standard deviation (SD). Statistics are for all valid samples collected during the two-year period shown in this table. The number of observations for south was 66, and the number of observations for north was 50.

Appendix 2: Subset from PHED for Exposures of Mixer/Loaders to Liquid Formulation Using a Closed System

Table 2-1. Description of PHED subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B	A
Liquid Type	Emulsifiable concentrate, aqueous suspension, microencapsulated, solution, or undiluted liquid	All emulsifiable concentrate
Mixing Procedure	Closed, mechanical pump or gravity feed	Closed

[a] Subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.

[b] Data quality for Airborne, Dermal Uncovered, Dermal Covered and Hand are all Grade A. Data quality grades are defined in the text and in Versar (1992).

Figure 2-1. Summary of results from the Pesticide Handlers Exposure Database (PHED) dermal subset [a]

```
             SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

 PATCH         MICROGRAMS PER LB AI MIXED
 LOCATION  |    Mean    Coef of Var  Geo. Mean      Obs.
HEAD <ALL>     1.6959    121.3279      .9508         22       Subset Name:
NECK.FRONT     1.5225    278.5222      .2418         22
NECK.BACK       .456     280.8991      .0729         22       S6DERMAL.MLOD
UPPER ARMS     1.3441     96.6967      .7988         21
CHEST          1.8416     93.4405     1.0577         16
BACK           1.8416     93.4405     1.0577         16
FOREARMS        .5474     98.5203      .3206         21
THIGHS         2.3398     81.9301     1.5773         16
LOWER LEGS     1.292      85.7276      .8778         21
```

[a] Subset criteria included actual and estimated head patches. Of the 22 head observations, all were actual.

Table 2-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (μg/lb AI handled)	Replicates in subset	Acute Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	13.6	21 [d]	4	1
Hand (with gloves)	5.72	31	4	1
Inhalation	0.128	27	4	1

[a] Results from subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.

[b] Multipliers are explained in the text and in Powell (2002).

[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).

[d] Median number of replicates was used in determining subset multipliers.

Table 2-3. Values Used in Exposure Calculations [a]

	Acute Exposure	Long-Term Exposure
Total Dermal (with gloves)	4(13.6) + 4(5.72) = 77.3 μg/lb AI handled	1(13.6) + 1(5.72) = 19.3 μg/lb AI handled
Total Dermal (no gloves) [b]	4(13.6) + 40(5.72) = 283 μg/lb AI handled	1(13.6) + 10(5.72) = 70.8 μg/lb AI handled
Inhalation	4(0.128) = 0.512 μg/lb AI handled	1(0.128) = 0.128 μg/lb AI handled

[a] Values from Table 2-2. Results rounded to three significant figures.

[b] Gloves assumed to provide 90% protection (Aprea *et al*, 1994); exposure of bare hands is calculated as ten times exposure of gloved hands.

Appendix 3: Groundboom Applicator; Open Cab

Table 3-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B	A,B,C
Liquid or Solid Type	Not specified	Emulsifiable concentrate or wettable powder
Application Method	Groundboom, Truck or Tractor	Groundboom, Tractor
Cab Type	Open Cab or Closed Cab with Open Window	Open Cab or Closed Cab with Open Window

[a] Subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.

[b] Data quality grades for Airborne, Dermal Uncovered, Dermal Covered and Hand are all Grade A or B, with the exception of one dermal replicate that has Dermal Uncovered Grade C (Dermal Covered for that replicate is Grade B). Data quality grades are defined in the text and in Versar (1992).

Figure 3-1. Summary of results from the PHED dermal subset [a]


```
            SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
   SCENARIO: Long pants, long sleeves, no gloves
  PATCH      MICROGRAMS PER LB AI SPRAYED
  LOCATION    Mean     Coef of Var  Geo. Mean    Obs.
 HEAD (ALL)   2.7891    136.1192    1.0464        33          Subset Name:
 NECK.FRONT   1.5763    167.9503     .3296        23
 NECK.BACK    1.0063    173.5765     .2335        29          S11DERMAL.APPL
 UPPER ARMS   1.6914     88.749     1.1637        32
 CHEST        1.7581     98.5154    1.1329        42
 BACK         3.0175    233.2361    1.3959        42
 FOREARMS     2.7301    419.1055     .564         32
 THIGHS       3.1255    185.5703    1.1806        33
 LOWER LEGS   2.1148    172.3425     .7466        35
```

[a] Subset criteria included actual and estimated head patches. Of the 33 head observations, all were actual.

Table 3-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Acute Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	20.9	33 [d]	4	1
Hand (no gloves)	45.6	29	4	1
Inhalation	1.18	22	4	1

[a] Results from subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.

[b] Multipliers are explained in the text and in Powell (2002).

[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).

[d] Median number of replicates was used in determining subset multipliers.

Table 3-3. Values Used in Exposure Calculations [a]

	Acute Exposure		Long-Term Exposure	
Total Dermal (with gloves) [b]	4(20.9) + 0.4(45.6) =	102 µg/lb AI handled	1(20.9) + 0.1(45.6) =	25.5 µg/lb AI handled
Total Dermal (no gloves)	4(20.9) + 4(45.6) =	266 µg/lb AI handled	1(20.9) + 1(45.6) =	66.5 µg/lb AI handled
Inhalation	4(1.18) =	4.72 µg/lb AI handled	1(1.18) =	1.18 µg/lb AI handled

[a] Values from Table 3-2. Results rounded to three significant figures.

[b] Gloves assumed to provide 90% protection (Aprea *et al*, 1994); exposure of gloved hands is calculated as one tenth exposure of bare hands.

Appendix 4: Aerial Applicator (Pilot) Applying Liquids

Table 4-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B,C	A,B,C
Liquid Type	Not specified	All emulsifiable concentrate
Solid Type	Exclude granular	none
Application Method	Fixed- or rotary-wing	All fixed-wing
Cab Type	Open Cab or Closed Cab with Open Window	Open Cab or Closed Cab with Open Window

[a] Subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.

[b] Data quality for Dermal Uncovered, Dermal Covered, and Hand were Grade A or C; Airborne data were Grade B or C. Data quality grades are defined in the text and in Versar (1992).

Figure 4-1. Summary of results from the Pesticide Handlers Exposure Database (PHED) subset [a]

```
        SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH       MICROGRAMS PER LB AI SPRAYED
LOCATION    Mean    Coef of Var  Geo. Mean  Obs.
HEAD (ALL)  4.212   118.2574     1.2438     10        Subset Name:
NECK.FRONT   .414   143.6715      .1169     10
NECK.BACK   .3124   139.1485      .0741     10        S17DERMAL.APPL
UPPER ARMS  8.5554  109.6232     5.7532     10
CHEST       6.3065  158.1987     2.1395     17
BACK        8.7497  141.5614     3.131      17
FOREARMS    2.7901  131.7516     1.1744     17
THIGHS      9.55    157.4126     3.4718     13
LOWER LEGS  7.4494  138.0769     3.3312     10
```

[a] Subset criteria included actual and estimated head patches. Of the 10 head observations, 7 were actual and 3 were estimated from nearby patches (Versar, 1992).

Table 4-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Acute Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	52.2	10 [d]	6	2
Hand (with gloves)	9.63	9	6	2
Inhalation	0.573	14	5	2

[a] Results from subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.

[b] Multipliers are explained in the text and in Powell (2002).

[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).

[d] Median number of replicates was used in determining subset multipliers.

Table 4-3. Values Used in Exposure Calculations [a]

	Acute Exposure	Long-Term Exposure
Total Dermal (with gloves)	6(52.2) + 6(9.63) = 371 µg/lb AI handled	2(52.2) + 2(9.63) = 124 µg/lb AI handled
Total Dermal (no gloves) [b]	6(52.2) + 60(9.63) = 891 µg/lb AI handled	2(52.2) + 20(9.63) = 297 µg/lb AI handled
Inhalation	5(0.573) = 2.86 µg/lb AI handled	2(0.573) = 1.15 µg/lb AI handled

[a] Values from Table 4-2. Results rounded to three significant figures.

[b] Gloves assumed to provide 90% protection (Aprea *et al*, 1994); exposure of bare hands is calculated as ten times exposure of gloved hands.

Appendix 5: Flagger, Liquids

Table 5-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B	A,B
Liquid Type or Solid Type	Not specified	Emulsifiable concentrate or dry flowable
Application Method	Fixed- or rotary-wing	All rotary-wing

[a] Subsets of Flagger data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Dermal Uncovered and Dermal Covered are all Grade A; Airborne and Hand data are all Grade A or B. Data quality grades are defined in the text and in Versar (1992).

Figure 5-1. Summary of results from the Pesticide Handlers Exposure Database (PHED) subset [a]

```
        SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

 PATCH      MICROGRAMS PER LB AI SPRAYED
 LOCATION     Mean   Coef of Var  Geo. Mean   Obs.          Subset Name:
HEAD (ALL)   11.3028   127.5702     5.6188      18
NECK.FRONT     .9533   134.3334      .5146      18          S7DERMAL.FLAG
NECK.BACK     1.4111   215.8529      .4931      18
UPPER ARMS    3.9285   195.1025      .8284      28
CHEST         5.1065   188.8378     1.0384      26
BACK          5.1065   188.8378     1.0384      26
FOREARMS      1.802    179.5283      .3837      28
THIGHS        4.0404   308.6996      .9165      26
LOWER LEGS    2.448    305.6618      .612       28
```

[a] Subset criteria included actual and estimated head patches. Of the 18 head observations, all were actual.

Table 5-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (μg/lb AI handled)	Replicates in subset	Acute Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand)	37.4	26 [d]	4	1
Hand (no gloves)	5.97	30	4	1
Inhalation	0.200	28	4	1

[a] Results from subsets of Flagger data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 5-3. Values Used in Scenario 7 Exposure Calculations [a]

	Acute Exposure	Long-Term Exposure
Total Dermal (with gloves)	4(37.4) + 0.4(5.97) = 152 μg/lb AI handled	1(37.4) + 0.1(5.97) = 38.0 μg/lb AI handled
Total Dermal (no gloves) [b]	4(37.4) + 4(5.97) = 173 μg/lb AI handled	1(37.4) + 1(5.97) = 43.4 μg/lb AI handled
Inhalation	4(0.200) = 0.800 μg/lb AI handled	1(0.200) = 0.200 μg/lb AI handled

[a] Values from Table 4-2. Results rounded to three significant figures.
[b] Gloves assumed to provide 90% protection (Aprea et al, 1994); exposure of gloved hands is calculated as one tenth exposure of bare hands.

Appendix 6: Mixer/Loader/Applicator; Low Pressure Hand Wand

Table 6-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]		
Airborne	A,B	A, B
Dermal and Hand	A, B, C	A, B, C
Liquid Type	Emulsifiable concentrate, aqueous suspension, microencapsulated, solution, or undiluted liquid	Solution or Microencapsulated
Application Method	Low Pressure Handwand	Low Pressure Handwand
Mixing Procedure	Not specified	All open

[a] Subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality grades are defined in the text and in Versar (1992).

Figure 6-1. Summary of results from the Pesticide Handlers Exposure Database (PHED) subset [a]

```
        SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

 PATCH         MICROGRAMS PER AVERAGE LB AI
 LOCATION        Mean    Coef of Var  Geo. Mean   Obs.
HEAD (ALL)     658.5361    136.7049    290.5017     80      Subset Name:
NECK.FRONT     137.9226    369.6483     18.9272     80
NECK.BACK       86.3274    429.9868     14.8349     79      S22DERMAL.MLAP
UPPER ARMS     111.8313    232.934      32.6211     10
CHEST          235.1875    185.929      48.9756     10
BACK           163.797     202.4421     41.5723     10
FOREARMS        40.9585    267.6492      9.412      10
THIGHS          37.9878    115.1859     27.6737      9
LOWER LEGS      66.9309    164.3135     30.0241      9
```

[a] Subset criteria included actual and estimated head patches. Of the 80 head observations, 10 were actual and 70 were estimated from nearby patches (Versar, 1992).

Table 6-2. PHED data from dermal, hand, and inhalation subsets for Scenario 22 [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Acute Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	1,570	10 [d]	6	2
Hand (with gloves)	10.4	10	6	2
Inhalation	22.8	10	6	2

[a] Results from subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 6-3. Values Used in Exposure Calculations [a]

	Acute Exposure	Long-Term Exposure
Total Dermal (with gloves)	6(1,570 + 10.4) = 9,480 µg/lb AI handled	2(1,570 + 10.4) = 3,160 µg/lb AI handled
Total Dermal (no gloves) [b]	6(1,570) + 60(10.4) = 10,000 µg/lb AI handled	2(1,570) + 20(10.4) = 3,350 µg/lb AI handled
Inhalation	6(22.8) = 137 µg/lb AI handled	2(22.8) = 45.6 µg/lb AI handled

[a] Values from Table 6-2. Results rounded to three significant figures.
[b] Gloves assumed to provide 90% protection (Aprea et al, 1994); exposure of bare hands is calculated as ten times exposure of gloved hands.

Appendix 7: Calculation of Parameters Used in Estimating Dermal Exposure to Workers Dipping Nursery Stock

1. K_p is the skin permeability coefficient, calculated as follows (U.S. EPA, 2004):

$$\log Kp = -2.80 + 0.66 \log Kow - 0.0056 \, MW$$

With MW of 221.3 and Log Kow of 1.42, the Kp is 0.000791 cm/hr for carbofuran.

2. B is the dimensionless ratio of two permeability coefficients, one for the stratum corneum (SC) and one for the epidermis (EPI). However, as explained by Bunge and Cleek (1995), the permeability coefficient for the epidermis is exceedingly difficult to determine: "Although experimental protocols exist for removing the EPI leaving an intact SC, techniques for removing the SC without damaging the EPI do not exist." Because the permeability of the epidermis is almost never known, Bunge and Cleek (1995) proposed four methods of estimating B without knowing the epidermal permeability, based on empirical data and theory. B is estimated from Method 4, which was the method recommended by Bunge and Cleek (1995):

$$B = P_{cw}[(MW)^{0.5}/(2.6 \text{ cm/hour})]$$

where P_{cw} is the estimated steady-state permeability of the stratum corneum from water, calculated as follows (Bunge and Cleek, 1995):

$$\log P_{cw} = -2.8 - 0.006(MW) + 0.74 \log K_{ow} = -3.077, \text{ and } P_{cw} = 0.00084 \text{ cm/hour. Thus,}$$

$$B = (0.00084)[(221.3)^{0.5}/(2.6)] = 0.00479.$$

3. τ is the lag time per event (hours). The lag time is how long it takes for a chemical to cross the skin, including both the SC and EPI (Bunge et al., 1995). τ is calculated as follows (U.S. EPA, 2004a):

$$\tau = 0.105 \times 10^{(0.0056 \, MW)}$$

For carbofuran, MW = 221.3. Thus,

$$\tau = 0.105 \times 10^{(0.0056 * 221.3)} = 0.105 \times 10^{(1.239)} = 0.105 \, (17.35) = 1.82 \text{ hours}$$

4. The equation for dermal exposure per event DA_{event} in RAGS-E is as follows (modified from Equation 3.3 in U.S. EPA (2004a), surface area term added to get result in mg/event rather than mg/cm2):

$$DA_{event} = FA * K_p * SA * C_w * (0.001L/cm^3) * [t/(1+B) + 2\tau((1+3B+3B^2)/(1+B)^2)]$$

where

DA_{event} is the absorbed dose per event (mg per event);
FA is the fraction absorbed water (dimensionless, default = 1);
SA (cm^2) is surface area of exposed skin;
C_w is the concentration of the pesticide in water (multiply by the appropriate protection factor);
t is the event duration (hours); and
other parameters are as defined above.

Appendix 7, Continued...

5. Absorbed daily dose is calculated by dividing the DA_{event} by body weight (BW).

Results of above calculations are summarized in Table 7-1.

Table 7-1. Dermal Carbofuran Exposure Estimates Calculated with Equations from RAGS-E [a]

Parameter	Value
K_p (cm/hr) [b]	0.000791
τ (hours) [c]	1.82
B [d]	0.00479
Hands	
DA_{event} (mg per day) [e]	9.97
ADD (mg/kg/day) [f]	0.142
Non-Hand Dermal	
DA_{event} (mg per day) [g]	80.6
Dermal ADD (mg/kg/day) [h]	1.15
Total Dermal	
Total Dermal ADD (mg/kg/day) [i]	1.29

[a] C_w = 12,000 mg/L for carbofuran (concentration in slurry prepared according to directions on Furadan® 4F product label). Concentration reaching skin is assumed to be reduced due to gloves and clothing; default protection factors are 90% for both (Thongsinthusak *et al.*, 1993a; Aprea *et al.*, 1994).

[b] Skin permeability coefficient (K_p) calculated from Equation 3.8 in U.S. EPA (2004a).

[c] Lag time for carbofuran to cross skin (τ) calculated from Equation A.4 in U.S. EPA (2004a).

[d] Ratio of permeability coefficients for the stratum corneum and the epidermis estimated from Equation A.1 in U.S. EPA (2004), which is also Method 4 in Bunge and Cleek (1995).

[e] Estimated hand exposure per day. Calculated from Equation 3.3 in U.S. EPA (2004a), SA = 904 cm^2 (surface area both hands; combined male and female medians from EPA, 1997). ET = 8 hours.

[f] ADD is absorbed daily dose. DA_{event} divided by 70 kg default body weight to obtain dermal dose (Thongsinthusak *et al.*, 1993).

[g] Estimated dermal exposure per day. Calculated from Equation 3.3 in U.S. EPA (2004a), SA = 7,306 cm^2 (surface area of chest/stomach, forearms, front of thighs and lower legs; combined male and female medians from EPA, 1997). ET = 8 hours.

[h] Dermal ADD is absorbed daily dose. AD_{Derm} divided by 70 kg default body weight to obtain dermal dose (Thongsinthusak *et al.*, 1993a).

[i] Total Dermal ADD is the sum of ADD for hands and Dermal ADD.

Appendix 8: Calculation of Parameters Used in Estimating Inhalation Exposure to Workers Dipping Nursery Stock

SWIMODEL estimates ambient vapor concentration of a chemical from its air-water partitioning using its unitless Henry's Law constant, which is calculated as follows (U.S. EPA, 2003):

$$C_{vp} = H' * C_w * (1,000 \text{ L/m}^3)$$

where

C_{vp} ($\mu g/m^3$) is the concentration of the pesticide in air;
H' is the unitless Henry's Law constant; and
C_w is the concentration of chemical in water ($\mu g/L$).

The unitless Henry's Law constant is calculated based on the Henry's Law constant in units of atm-m^3/mole using the following equation:

$$H' = H/(R * T)$$

where

H' is the unitless Henry's Law constant;
H is the aqueous Henry's Law constant (atm-m^3/mole);
R is the gas constant (8.19×10^{-5} atm-m^3/mole-K); and
T is the ambient air temperature (degrees Kelvin, or 273 added to degrees Celsius).

SWIMODEL calculates the potential dose rate in mg per event ($AD_{Inhalation}$) as:

$$AD_{Inhalation} = Cvp * ET * IR * (1 \text{ mg}/1,000 \text{ } \mu g)$$

where

C_{vp} ($\mu g/m^3$) is the concentration of the pesticide in air;
ET (hrs/event) is exposure time; and
IR (m^3/hr) is inhalation rate.

However, carbofuran products contain additives to increase water solubility. Because of this, the vapor concentration calculated from the SWIMODEL equation is quite high, perhaps above concentrations that could actually occur. To check this, the equation used to estimate vapor pressure by the gas saturation method (U.S. EPA, 1996b) can be re-arranged to provide an estimate of saturated vapor concentration based on reported vapor pressure. The equation is given below.

$$C_{sat} = [(VP/760) * MW * (1,000 \text{ mg/g})(1,000 \text{ L/m}^3)]/R*T$$

where

C_{sat} ($\mu g/m^3$) is the saturated concentration of the pesticide in air;
MW is the molecular weight;
R is the gas constant (8.19×10^{-5} atm-m^3/mole-K); and
T is the ambient air temperature (degrees Kelvin, or 273 added to degrees Celsius).

The estimated C_{sat} is given in Table 8-1. This value is considerably lower than the estimated C_{vp}, suggesting that C_{vp} is unrealistically high. Therefore, C_{sat} was used in calculating inhalation exposure. This approach is used by another model to estimate inhalation exposure (U.S. EPA, 2004b).

Appendix 8, Continued...

Table 8-1. Inhalation Carbofuran Exposure Estimate Based on SWIMODEL Equations [a]

Parameter	Value
H' [b]	2.08×10^{-8}
C_{vp} [c]	250
C_{sat} [d]	36.6
$AD_{Inhalation}$ (mg per day) [e]	0.0732
Inhalation ADD (mg/kg/day) [f]	0.00105

[a] C_w = 12,000 mg AI/L for carbofuran (concentration in slurry prepared according to directions on Furadan® 4F product label).
[b] Unitless Henry's Law constant. See text for equation.
[c] Calculated concentration of pesticide in air. See text for equation.
[d] Saturated vapor concentration, based on a vapor pressure of 6×10^{-8} mm Hg @ 25°C (Alvarez, 1989). See text for equation.
[e] Estimated inhalation exposure per day. See text for equation. C_{sat} used for C_{vp}, IR = 20 m³/day, ET = 1 day. A default protection factor of 90% is factored in for use of a respirator (NIOSH, 1987).
[f] ADD is absorbed daily dose. To calculate, $AD_{inhalation}$ was divided by 70 kg default body weight to obtain dose (Thongsinthusak *et al*., 1993a).

A default value of 20 m³/day was used for IR (Andrews and Patterson, 2000); this value assumes moderate to heavy activity during an 8 hour workday. Because IR is given for the workday rather than on an hourly basis, ET is set to 1 day in the exposure calculation. This result is multiplied by 0.1 for use of a respirator (NIOSH, 1987). The inhalation contribution to the ADD is calculated by dividing by the default body weight of 70 kg (Thongsinthusak *et al*., 1993a). Exposure estimates are given in Table 8-1.