ENVIRONMENTAL FATE OF INDOXACARB

Revised by Joy Lyn Dias
Environmental Monitoring Branch
Department of Pesticide Regulation
1001 I Street
Sacramento, CA 95812-4015

August 2006

INTRODUCTION

This document reviews the environmental fate and environmental effects of the insecticide indoxacarb, CAS No. 173584-44-6. The chemical name of indoxacarb is (S)-methyl 7-chloro-2,5-dihydro-2- [[(methoxycarbonyl) [4(trifluoromethoxy)phenyl]amino]carbonyl] indeno[1,2-e][1,3,4]oxadiazine-4a(*3H*)-carboxylate. Indoxacarb is a member of the new oxadiazine class of insecticides that act by inhibiting sodium ion entry into nerve cells, resulting in the paralysis and death of target insect pests.

Indoxacarb was developed by E. I. du Pont de Nemours and Company (DuPont). It was initially registered by the U.S. Environmental Protection Agency (U.S. EPA) in October 2000 and was designated a "reduced-risk" pesticide (U.S. EPA, 2000). In California the first product containing indoxacarb was registered for use in January 2001. The current DuPont products registered for use in California that contain indoxacarb are Avaunt® and Steward® for agricultural use and Advion™ Fire Ant Bait for use by commercial applicators. Several other companies have recently registered products containing indoxacarb for household use: Chemsico Ant Control 4I, Chemsico Ant Control I, Chemsico Insect Bait 16I, Chemsico Roach Control I, Hot Shot Maxattrax Ant Bait 2, Hot Shot Maxattrax Ultra Brand Nest Destroyer Roach Bait, Real-Kill Ant Bait, and Spectracide Fire Ant Killer Plus Preventer Bait Once and Done! (California Department of Pesticide Regulation, 2005a).

Indoxacarb has several formulations including tablet, broadcast granule, water dispersible granule, and suspension concentrate. The technical material is a white powered solid (Crop Protection Handbook, 2003). The name indoxacarb refers to the S-isomer of the molecular structure, which has been designated as DPX-KN128 by DuPont (Figure 1). The R-stereoisomer, DPX-KN127, does not display insecticidal activity. DPX-MP062 is a 75:25 mixture of the two isomers, while DPX-JW062 is a 50:50 mixture. DPX-JW062 is a less effective insecticide than DPX-MP062 due to the lower levels of the active isomer, DPX-KN128, in the compound. Most of the physicochemical and original field trial data were obtained using the 50:50 isomer mixture, DPX-JW062 (Brugger, 1997), although the most recent studies have used DPX-MP062 (Singles, 2004). The amount of indoxacarb in registered products ranges from 14.5% to 30 % in agricultural use products and from 0.016% to 0.1% in commercial and household use products (California Department of Pesticide Regulation, 2005a). Bridging data for the isomeric mixtures was determined using soil and aquatic metabolism studies because it is generally believed that different biological degradation pathways are likely for different stereoisomers (Hetrick et al., 2005). Data from the bridging studies indicate that there is no difference in the degradation of the two isomers (DPX-KN127 and DPX-KN128) in water, soil, and sediment, in both irradiated and non-irradiated studies. There are sufficient data to support the bridging of abiotic and biotic degradation for isomers of indoxacarb (Singles, 2004; Hetrick et al., 2005). The enantiomers of IN-JT333 have also been shown to degrade at the same rate in soil (Spare, 1997).

Indoxacarb, a broad spectrum foliar insecticide, is registered for use on a broad range of crops, which include fruits (apples, pears, and tomatoes), vegetables (bok choy, broccoli, Brussels sprouts, cabbage, cauliflower, Chinese cabbage, corn, eggplant, kohlrabi, peas, peppers, potatoes, and lettuce), soybeans, alfalfa, and cotton. It controls or suppresses many insects, including beet armyworm, cabbage looper, corn earworm, diamondback moth, fall armyworm, imported cabbageworm, southern armyworm, tomato pinworm, and tomato fruitworm (DuPont, 2006; California Department of Pesticide Regulation, 2006). In 2004, 36,930 lbs a.i. of indoxacarb were used on 493,004 total agricultural acres in California, which was a decrease of 52 percent from 2003 usage. According to the California Department of Pesticide Regulation, the reduction in use was probably due to fewer problems with beet armyworm and lygus. The majority of indoxacarb usage in California occurred on cotton, alfalfa, and tomatoes in Fresno, Kings, and Imperial counties (California Department of Pesticide Regulation, 2005b). Application rates for agricultural crops range from 0.045 to 0.11 pounds of active ingredient per acre (lbs a.i./acre) with a maximum of 2 to 4 applications per year. Application rates for fire ant control are even lower with a maximum of two applications per year at rates from 0.000675 to 0.0027 lbs a.i./acre (Hetrick et al., 2005).
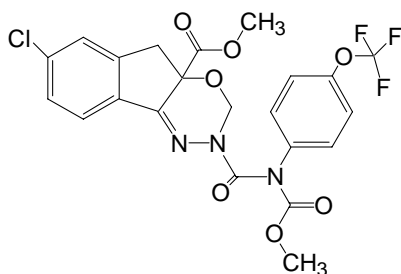
Indoxacarb possesses both larvicidal and ovicidal activity. As a larvicide, it is active by ingestion and/or absorption into the insect. The importance of the entry route varies with the species affected and the crop situation. Once indoxacarb is absorbed or ingested, feeding cessation generally occurs within 2 to 8 hours. Indoxacarb kills by binding to a site on the sodium channels and blocking the flow of sodium ions into nerve cells resulting in impaired nerve function, feeding cessation, paralysis, and death (Brugger, 1997). It may take days for insects to die. Indoxacarb, a pro-insecticide, must be metabolized first in order to become toxic. The pesticidally active enantiomer DPX-KN128 is rapidly degraded in the insect gut after ingestion to the much more insecticidally active metabolite IN-JT333, also referred to as DCJW (*N*-decarbomethoxyllated DPX-JW062) in the literature. An esterase or amidase is required to complete the conversion (Wing et al., 1998; Silver and Soderlund, 2005). IN-JT333 is more effective than indoxacarb at blocking sodium channels (Tsurubuchi and Kono, 2003) resulting in a higher toxicity than the parent compound (Brugger, 1997).

Many insects have developed resistance to conventional pesticide chemistries, such as organophosphates, carbamates, and pyrethroids. To combat these pesticide resistant pests new chemistries have been developed with novel modes of action unrelated to previous chemical classes to replace the old chemistries. Indoxacarb is a non-systemic, synthetic organophosphate replacement insecticide that has good field activity against a number of Lepidoptera pests, as well as certain Homoptera and Coleoptera pests. Indoxacarb is converted very rapidly to IN-JT333 in Lepidoptera (Wing et al., 1998) and is converted to IN-JT333 at slower but toxicologically significant rates in other key sucking insect pest orders. The rate of bioactivation is a critical factor in determining the speed and ultimate toxicity of the compound in different insect species. Several sucking insects are capable of absorbing and bioactivating indoxacarb after either dermal or oral administration, but do so much more slowly than the Lepidoptera (Wing et al., 2000). Indoxacarb affects insects from direct exposure when the pesticide is sprayed on the foliage and through ingestion of treated foliage or fruit.

Indoxacarb and IN-JT333 possess different profiles in their potency in blocking sodium channels and the reversibility of the blocking effects in mammalian neurons. The different profiles would partially explain the high selective toxicity of indoxacarb between target insects and non-target organisms (Tsurubuchi and Kono, 2003; Zhao et al., 2003; Silver and Soderlund, 2005). In insects (e.g., Lepidopterans) the metabolism of the parent to IN-JT333 is very rapid. However, in mammals (e.g., rats) conversion of the parent to IN-JT333 is a minor pathway, and IN-JT333 is

extensively metabolized and eliminated in the urine (Brugger, 1997; Hetrick et al., 2005). The extent to which metabolism of the parent compound to IN-JT333 occurs in wild birds, fish, and aquatic invertebrates is presently not quantified (Hetrick et al., 2005).

Molecular Structure:

Chemical Formula: $C_{22}H_{17}ClF_3N_3O_7$

Physical-Chemical Properties:

Table 1. Physical and chemical properties of indoxacarb. Data obtained from Brugger (1997) are denoted with superscript 'a' and data obtained from approved studies submitted to the California Department of Pesticide Regulation (CDPR) Pesticide Chemistry Database (2005c) are indicated with superscript 'b'.

Property	Value
Molecular weight[a]	527.87 g/mole
Water solubility[b]	0.2 mg/L (25º C at pH 7.0)
Vapor pressure[b]	$<1.0 \times 10^{-7}$ mmHg (25 ºC)
Hydrolysis half-life[b]	>30 days (pH 5)
	38 days (pH 7)
	1 day (pH 9)
Aqueous photolysis half-life[b]	3.16 days (pH 5)
Aerobic soil degradation[b]	
Phase I	4.5 days (25 ºC)
	7.8 days (20 ºC)
Phase II	42.7 days (25 ºC)
	117 days (20 ºC)
Anaerobic soil degradation[b]	
Phase I	12.8 days (25 ºC)
Phase II	402 days (25 ºC)
Soil photolysis half-life[b]	139 days
Field dissipation half-life[b]	6-114 days (median 20.1)
Henry's law constant[a]	$<6 \times 10^{-10}$ atm-m^3/mol (25 ºC)
Octanol-water coefficient[b]	
log K_{ow}	4.65
K_{ow}[b]	4.50×10^4
Soil adsorption coefficient	
K_{oc}[ab]	2200-9400
K_d[b]	26-94

Toxicity:

Table 2. Selected toxicity data for indoxacarb and degradates[a]. Obtained from U.S. Environmental Protection Agency (Hetrick et al., 2005).

Species	Study Type	Concentration
Freshwater Fish		
Oncorhynchus mykiss (Rainbow trout)	Acute Toxicity LC_{50}	0.65 mg/L
	Chronic LOEL	0.25 mg/L
	Chronic NOEL	0.15 mg/L
	Acute Toxicity LC_{50} IN-JT333	0.024 mg/L
	Chronic Toxicity LC_{50} IN-JT333	0.0055 mg/L
	Acute Toxicity LC_{50} IN-MP819	>0.368 mg/L
	Chronic Toxicity LC_{50} IN-MP819	0.0849 mg/L
Cyprinus carpio (Carp)	Acute Toxicity LC_{50}	1.02 mg/L
Ictalurus punctatus (Channel catfish)	Acute Toxicity LC_{50}	0.29 mg/L
Estuarine/Marine Fish		
Cyprinodon variegatus (Sheepshead minnow)	Acute Toxicity LC_{50}	>0.37 mg/L
	Chronic LOEL	0.042 mg/L
	Chronic NOEL	0.017 mg/L
Freshwater Aquatic Invertebrates		
Daphnia carinata	Acute Toxicity EC_{50}	2.94 mg/L
Daphnia magna (Water flea)	Acute Toxicity EC_{50}	0.60 mg/L
	Chronic LOEL	0.19 mg/L
	Chronic NOEL	0.075 mg/L
	Acute Toxicity EC_{50} IN-JT333	>0.029 mg/L
	Chronic Toxicity LC_{50} IN-JT333	0.0036 mg/L
	Acute Toxicity LC_{50} IN-MP819	0.0640 mg/L
	Chronic Toxicity LC_{50} IN-MP819	0.0080 mg/L
Estuarine/Marine Aquatic Invertebrates		
Crassostrea virginica	Acute Toxicity EC_{50}	0.203 mg/L
Mysidopsis bahia	Acute Toxicity EC_{50}	0.0542 mg/L
	Chronic LOEL	0.0407 mg/L
	Chronic NOEL	0.0184 mg/L
Non-Target Aquatic Plants		
Anabaena flos-aquae (Algal species)	Acute Toxicity EC_{50}	>1.93 mg/L
Navicula pelliculosa (Diatom)	Acute Toxicity EC_{50}	>1.68 mg/L
Lemna gibba (Duckweed)	Acute Toxicity EC_{50}	>0.084 mg/L
Birds		
Anas platyrhynchos (Mallard duck)	Subacute 5-day dietary LC_{50}	>5620 mg/kg-diet
Colinus virginianus (Bobwhite quail)	Acute single oral dose LD_{50}	98 mg/kg
	Subacute 5-day dietary LC_{50}	808 mg/kg-diet
Mammals		
Rattus norvegicus (Rat female)	Acute oral LD_{50}	179 mg/kg
Rattus norvegicus (Rat male)	Acute oral LD_{50}	843 mg/kg
Non-Target Insects		
Apis mellifera (Honey bee)	Acute LD_{50} 48-hr contact	0.18 ug/bee

[a]Data refers to technical parent material unless specified.

Water Quality Standards: U.S. EPA has not established maximum contaminant levels (MCLs) for dietary exposure to indoxacarb through drinking water, however drinking water levels of comparison (DWLOCs) were calculated. DWLOCs are the theoretical maximum concentration for a pesticide in drinking water that would be acceptable considering the estimated exposure to that pesticide from other sources such as food and residential use. DWLOCs are then used as a point of comparison against modeled estimated environmental concentrations (EECs) of a pesticide in water. U.S. EPA concluded that exposures to indoxacarb in drinking water would not result in unacceptable human health risk since the EECs for surface water (Table 4) and ground water (Table 5) are less than the calculated DWLOCs listed below (U.S. EPA, 2004).

Table 3. Drinking water levels of comparison (DWLOC) for indoxacarb.

Chronic exposure	40-480 ug/L
Acute exposure	400-3700 ug/L

ENVIRONMENTAL FATE

Air

Indoxacarb is relatively non-volatile with a low vapor pressure of $<1.0 \times 10^{-7}$ mmHg at 25 ºC (Table 1). The low vapor pressure indicates vaporization is not a significant dissipation mechanism in the environment. The Henry's law constant of $<6 \times 10^{-10}$ atm-m^3/mol at 25 ºC (Table 1) indicates that indoxacarb has a low potential to volatilize from aqueous solution or moist soils (Cobranchi and Schmuckler, 1997). A laboratory study of DPX-JW062 volatilization from plant and soil surfaces found that spray applications to lettuce similar to those common in agricultural practice resulted in only small amounts of volatilization, <3% in seven days (Kubiak, 1996).

Water/Sediment

Indoxacarb undergoes alkaline-catalyzed hydrolysis, photodegradation in water, and microbial mediated degradation. In near-neutral aerobic aquatic systems, indoxacarb degraded with half-lives ranging from 18 to 34 days. Under anaerobic conditions, indoxacarb was persistent (Hetrick et al., 2005) and the transient hydrolysis product IN-KT413 (Figure 1) was formed (Smyser, 2002a). Indoxacarb hydrolysis rates increased with increasing pH. The half-life of DPX-JW062 at pH 5, 7, and 9 was calculated to be approximately 500 days, 38 days, and 1 day, respectively (Ferraro and McEuen, 1996). The half-life of DPX-MP062 at pH 5, 7, and 9 was similar at 607 days, 22 days, and 0.25 days, respectively (Lentz, 2002a). At pH 9, the major degradation products were IN-KT413 and IN-MF014 (Figure 1 and Figure 2) (Singles, 2004). Hydrolysis is a major dissipation route for indoxacarb in the environment.

In aqueous photolysis studies, radiolabeled DPX-JW062 and DPX-MP062 were rapidly degraded by simulated sunlight resulting in a complete loss of the central nucleus of the parent molecule. The short aqueous photolysis half-life of three days suggests low persistence in aquatic systems. This indicates that chronic exposures in aquatic systems may not be significant (Ferraro and McEuen, 1997; Lentz, 2002b). The major degradation products of DPX-MP062 were IN-C0639, IN-KB687, IN-MA573, IN-MF014, and IN-MH304 (Figure 1 and Figure 2) (Lentz, 2002b).

A study of laboratory soil photolysis found that degradation on Tama silt soil samples was slow under exposure to simulated sunlight. The soil photolysis half-life using natural sunlight was calculated to be 139 days. The major degradation product was IN-KB687 and the minor

degradation product was IN-JT333 (Figure 1). Given the rapidity at which DPX-JW062 is degraded hydrolytically, 38 days at pH 7, and in aerobic soil (Table 1), soil photolysis probably plays only a minor role in the environment (Berg, 1997).

No ground water or surface water monitoring data currently exists for indoxacarb because it is a relatively new active ingredient (Hetrick et al., 2005).

Surface Water: The fate of DPX-MP062 in two aquatic sediment systems was studied in natural locations. DPX-MP062 degraded in the water phase and partitioned to the sediment where it was further degraded to other metabolites that eventually were incorporated into the sediment organic fraction and mineralized to CO_2. Dissipation of DPX-MP062 from both the overlying water and the total water/sediment system was rapid with a dissipation half-life (DT_{50}) of 1-2 days and 3-12 days, respectively. IN-KT413 (Figure 1), the only major degradation product in the water, had a DT_{50} of 26 days. At least ten extractable metabolites were formed in the sediment with DT_{50} values ranging from 1 day to 346 days for the major degradation products IN-JT333, IN-KT413, IN-MP819, and IN-MS775 (Figure 1 and Figure 3) (Shaw, 2002; Hetrick et al., 2005).

The U.S. EPA screening model GENEEC (GENeric Estimated Exposure Concentration) Tier 1 calculations for cotton, the highest exposure application method, predicted a peak DPX-MP062 concentration of 1.1-1.2 ug/L in surface water with a rapid decline to lower values over time (e.g., 56-day time-weighted average concentration was 0.06-0.07 ug/L). This calculation represents an estimate of the potential concentrations that would be observed as a result of runoff, erosion, and drift from a ten-hectare field directly into a one-hectare pond adjacent to a treated field. The low initial surface water concentrations and the rapid rate of degradation in aquatic systems present low exposure risk to aquatic organisms (Russell, 1997). Using the Tier II PRZM/EXAMS (Pesticide Root Zone Model/Exposure Analysis Modeling System) model, U.S. EPA predicted the peak and average concentration of indoxacarb and a limited number of degradates in surface water (Table 4) (U.S. EPA, 2004). PRZM is used to simulate pesticide transport due to runoff and erosion from a ten-hectare agricultural field and EXAMS considers the environmental fate and transport of pesticides in surface water and predicts EECs in a standard pond (10,000-m^2 pond, 2-m deep), with the assumption that the small field is cropped at 100% (Hetrick et al., 2005).

Table 4. Estimated environmental concentrations (EECs) for indoxacarb and IN-JT333 in surface water. Data obtained from the PRZM/EXAMS model (U.S. EPA, 2004) and the GENEEC Tier 1 model (Hetrick et al., 2005).

Exposure Estimate	Indoxacarb EEC	IN-JT333 EEC	IN-MP819 EEC
Acute exposure	13.7 ug/L	0.57 ug/L	0.016 ug/L
Chronic exposure	3.7 ug/L	0.36 ug/L	0.001 ug/L

Ground Water: U.S. EPA conducted Tier 1 calculations using the screening model SCI-GROW (Screening Concentration In Ground Water) to estimate pesticide concentrations in vulnerable ground water areas, i.e. shallow aquifers with sandy, permeable soils and substantial rainfall or irrigation to maximize leaching. The SCI-GROW estimate is based on environmental fate properties of the pesticide, the maximum application rate, and existing data from small-scale prospective ground-water monitoring studies at sites with sandy soils and shallow ground water (U.S. EPA, 2006). Tier 1 calculations of the potential concentrations of DPX-MP062 in shallow ground water indicated a negligible leaching potential even in a worst-case setting with a peak concentration of approximately 0.008 ug/L (Russell, 1997). More recent calculations by U.S. EPA estimated that acute and chronic environmental concentrations for indoxacarb and a limited

number of degradates in shallow ground water are not likely to exceed 0.02 ug/L (Table 5) (U.S. EPA, 2004; Hetrick et al., 2005).

Table 5. Estimated environmental concentrations (EECs) for indoxacarb in ground water. Data obtained from the SCI-GROW model (U.S. EPA, 2004).

Exposure Estimate	Indoxacarb EEC
Acute exposure	0.02 ug/L
Chronic exposure	0.02 ug/L

Indoxacarb is moderately hydrophobic with a low water solubility of 0.2 mg/L and a log K_{ow} of 4.6 (Table 1). This, coupled with a moderately high soil sorption coefficient K_{oc} of 2200-9400 (Table 1), indicates a relatively low probability of leaching into ground water. Although some of the major degradates of indoxacarb had very low K_{oc} values, they also had short half-lives that reduce their probability of leaching into ground water (Table 6).

Table 6. Comparison of average DT_{50} and K_{oc} for the major degradates of indoxacarb (Singles, 2004; Hatzenbeler, 2002a, 2002b; Walsh, 2003; Herczog, 2002; Caldwell, 2002; Singles, 2002a).

Degradate	Average DT_{50} (days)	Average K_{oc} (mL/g)
IN-JT333	19.9	17,300
IN-JU873	38.1	12,816
IN-KG433	2.4	400
IN-KT413	2.6	422
IN-MK638	11	321
IN-MK643	235.2	692
IN-ML438	43.4	3,028

Soil

Dissipation of DPX-MP062 proceeds as a mixture of degradation, incorporation into the soil organic fractions, and mineralization to CO_2 (Mellor, 2003). Indoxacarb has a biphasic dissipation pattern with a rapid degradation rate followed by a slower degradation rate making the selection of a suitable soil degradation half-life difficult (Hetrick et al., 2005). In anaerobic soil at 25 ºC, the rate of indoxacarb degradation (DT_{50} in the total system of 186 days) was slower than the rate of degradation in aerobic soils (Table 1) (Smyser, 2002a). Indoxacarb is considered moderately persistent with aerobic half-lives ranging from <1 day to 693 days and anaerobic half-lives ranging from 147 to 233 days (U.S. EPA, 2000; Singles, 2004). There was no obvious correlation between the rate of degradation of indoxacarb and soil pH. The degradation rates of DPX-JW062, DPX-MP062, DPX-KN128, and IN-KN127 were found to be equivalent in aerobic soils (Singles, 2004). The breakdown product IN-JT333 (Figure 1) was first detected in aerobic silt loam soil at 1 day after DPX-JW062 application, reached maximum concentration of 14% of applied radioactivity within 5 days, and then degraded with DT_{50} of 8-12 days using non-linear first-order kinetics. The other major degradation product, IN-KG433 (Figure 1), had a DT_{50} of less than one day. The remainder of the radioactive degradate profile was identical for both indanone-labeled DPX-JW062 and DPX-MP062. Minor degradation products were IN-JU873, IN-KB687, IN-KT413, IN-MK638, IN-MK643, and IN-ML438 (Figure 1 and Figure 4) (Rhodes, 1997; Singles, 2002b). The rates of degradation for the major metabolites ranged from an average DT_{50} of 2.4 days for IN-KG433 to an average DT_{50} of 235.2 days for IN-MK643 (Table 6 and Figure 1) (Russell, 2004).

Indoxacarb undergoes rapid decomposition in terrestrial environments through microbial degradation (Brugger, 1997). Field soil dissipation studies found that indoxacarb applied to bare soil under actual field-use conditions dissipated with DT_{50} values of 60 and 63 days in Florida and California, respectively (Vincent et al., 1997). The degradation rates also varied by season with summer applications degrading more rapidly than autumn and winter applications (Rühl, 1997; Smyser, 2002b). The same conclusions were reported in the DPX-JW062 field soil dissipation study for similar soil types. DPX-JW062 dissipated with a DT_{50} of 9-62 days according to first-order kinetic modeling at three sites although a fourth site in California degraded significantly slower with a DT_{50} of 193 days, presumably due to a lack of microbial activity in the soil (Rühl, 1997; Smyser, 2002b). Degradation products of indoxacarb had different half-lives in aerobic soils: IN-KT413 and IN-MK638 were non-persistent (DT_{50} = 1.3-16.2 days); IN-KG433 and IN-JU873 were non-persistent to moderately persistent (DT_{50} = 10.5-58.7 days); and IN-MK643 was persistent (DT_{50} = 141.5-346.6 days) (Hetrick et al., 2005).

In a soil column leaching study including aged soils, DPX-MP062 and its degradates (IN-JT333, IN-JU873, IN-KG433, and IN-MK643) were nearly immobile on aged soil columns (Fetterman and Chrzanowski, 1997). During field soil dissipation studies of indoxacarb applied to bare ground there were four samples in the 15-30 cm soil cores with quantifiable indoxacarb residues in California. No quantifiable residues of IN-KG433 were observed at any depth and IN-JT333 was rarely observed at quantifiable levels at 0-15 cm, indicating that the dissipation of indoxacarb can be described by measuring only the parent compound (Vincent et al., 1997). Further tests for indoxacarb and IN-JT333 indicated that there were no quantifiable residues between 30 and 60 cm (Bonino et al., 1999). Although IN-JT333 was detected in all field dissipation studies and some leaching of the parent and degradation products occurred, there were no detections below 45 cm (Hetrick et al., 2005). None of the metabolites that were found in soil metabolism, hydrolysis, or photolysis studies were detected under field conditions at concentrations greater than 10% of applied radiolabel (Singles, 2004; Hetrick et al., 2005).

In a study of five Hawaiian soils, indoxacarb became quickly and tightly bound to the five soils tested within 90 days. Indoxacarb recoveries decreased for all soils from 3 to 30 days after incubation due to low water solubility and strong attraction to the carbon fraction in the soils, followed by fairly constant recoveries from 60 to 90 days (Campbell et al., 2005). Measurements of the sorption of DPX-JW062 and IN-JT333 to soil were hampered by both the low water solubility and the instability of both compounds in the test system. The sorption data indicated that ^{14}C-labeled DPX-JW062 and IN-JT333 had very low mobility potential with the average K_{oc} value for DPX-JW062 measured at 5,125 mL/g and 17,300 mL/g for IN-JT333. The K_d values of the four soil types indicated that the mobility of DPX-JW062 and IN-JT333 were not correlated with any soil characteristic (Smyser, 2002c). For the other major soil metabolites K_{oc} data were generated with average K_{oc} values ranging from 321 mL/g to 17,300 mL/g (Table 6).

Biota

Ecological Risk Evaluation: Risk quotients (RQs) are calculated from a ratio of estimated environmental concentrations (e.g. EEC) to acute and chronic toxicity test effect levels (e.g. LC_{50}) (e.g., RQ = EEC/LC_{50}, RQ = EXPOSURE/TOXICITY) for various wildlife species. RQs are then compared to levels of concern (LOCs), regulatory risk criteria established by the U.S. EPA to suggest potential for risk to non-target organisms and the need to consider regulatory action. The criteria evaluate the likelihood of adverse ecological effects to non-target species when these LOCs are exceeded. Generally, the higher the RQ, the greater the potential risk. LOCs currently address the following risk presumption categories: (1) acute high – potential for acute risk is high, regulatory action may be warranted in addition to restricted use classification,

(2) acute restricted use –potential for acute risk is high, but may be mitigated through restricted use classification, (3) acute endangered species – endangered species may be adversely affected if actual exposure occurs, and (4) chronic risk – potential for chronic risk is high, regulatory action may be warranted (Brugger, 1997; Hetrick et al., 2005).

Fish and Aquatic Invertebrates: Indoxacarb, the DPX-KN127 isomer, and associated degradates are moderately to very highly toxic to freshwater fish and invertebrates on an acute basis with $LC_{50}s$ (50 percent lethal concentrations) ranging from 0.024 to 2.94 mg/L (Table 2). They are also moderately toxic to very highly toxic to estuarine/marine fish and invertebrates on an acute basis with $EC_{50}s$ (50 percent effective concentrations) ranging from 0.0542 to >0.37 mg/L (Table 2). Chronic toxicities range from 0.0036 to 0.25 mg/L for freshwater fish and invertebrates and from 0.017 to 0.042 mg/L for estuarine fish and invertebrates (Table 2) (U.S. EPA, 2000; Hetrick et al., 2005). Acute restricted use and endangered species levels of concern (RQ = 0.1) are exceeded by estuarine/marine invertebrate acute risk quotients calculated for indoxacarb (RQ = 0.1) and the degradate IN-JT333 (RQ = 0.2) for the two highest exposure concentrations (peanuts and alfalfa). Indoxacarb and its degradate IN-JT333 are not expected to reach surface water concentrations high enough to trigger acute risk concerns (RQ = 0.5) or chronic concerns (RQ = 1) in fish or invertebrates in either freshwater or estuarine/marine systems (Hetrick et al., 2005). However, due to the very high toxicity of indoxacarb to some estuarine/marine fish and invertebrates, direct exposure or runoff into surface waters could be of concern.

Calculated fish bioconcentration factors for DPX-JW062 are 395-504 for edible tissues, 1568-2081 for nonedible tissues, and 1044-1351 for whole fish tissues. The depuration half-life of bioaccumulated indoxacarb residues ranged from 6.55 to 7.88 days. Minor degradation products (<10% recovered) were IN-JU873, IN-KG433, IN-KT319, and IN-ML811. Degradation products IN-JT333 and IN-MP819 are expected to exhibit ecotoxic effects. Additionally, IN-MP819 has been shown to exhibit greater toxicity to aquatic invertebrates than the parent indoxacarb (Hetrick et al., 2005).

Vegetation: Indoxacarb has no reported adverse effects on non-target terrestrial plants. Phytotoxic effects on eight crops were not observed in field efficacy testing at application rates approximately equivalent to its intended field use rate on vegetables of 0.065 lbs a.i./acre (Brugger, 1997).

DPX-MP062 degraded moderately rapidly in and on plant leaves and fruits. The measured DT_{50} on leaves and fruits of the vegetable crops ranged from 2 to 34 days (average 18 days). Based on the low use rate of DPX-MP062 and its rapid dissipation in plants, dietary exposure to non-target organisms inside and outside the application area is expected to be very low. Studies with aquatic algae and duckweed indicated no measurable toxicity at levels >1.93 mg/L and >0.084 mg/L, respectively (Table 2) Brugger, 1997.

Metabolism studies on lettuce, tomatoes, and cotton found no major metabolites detectable in any of the rinses or extracts (Gaddamidi and Hashinger, 1997; Brown and Young, 1997; Scott and Guseman, 1997). Chromatographic evidence indicated that DPX-JW062 metabolized or degraded to more polar compounds on cotton. These residues generally represented 1-3% of total radioactive residues. The dissipation of DPX-JW062 in cotton was primarily due to growth dilution, with wash off and metabolism playing less significant roles (Scott and Guseman, 1997).

Birds: Indoxacarb is moderately toxic to avian species on a subacute dietary basis and on an acute oral basis (Table 2), and the metabolite IN-JT333 is slightly toxic to avian species on an acute oral basis (U.S. EPA, 2000). The highest dietary RQ for DPX-MP062 for birds (RQ =

0.13) is lower than the LOC for most species (LOC = 0.5). However, the LOC for endangered species (LOC = 0.1) was slightly exceeded (Brugger, 1997).

Mammals: Mammalian toxicity studies were extrapolated from laboratory studies on rats ([Table 2](#)) (U.S. EPA, 2000). Mammalian chronic risk LOCs were exceeded for multiple applications for several crop scenarios in three wildlife food items with RQs ranging from 1.02 to 2.82 (LOC = 1.0). In addition to chronic risk from reproductive effects, chronic risk resulting from hemolytic effects is also possible, however, the importance of these effects in wildlife populations is not certain (Hetrick et al., 2005).

DPX-MP062 has moderate acute toxicity to mammals. The highest short-term dietary RQ for most mammals is below the LOC (RQ = 0.37, LOC = 0.5), however, dietary RQs for herbivores and small-bodied insectivores in cotton, pome fruit, and vegetable crops exceeded the LOC for endangered species (LOC = 0.1) (Brugger, 1997). No acute LOCs are exceeded for any use scenario or any weight class of mammal when risk to granivorous mammals or broadcast granular applications to control fire ants is considered (Hetrick et al., 2005). IN-JT333 is highly toxic to rats, but is predicted to be safe in short-term exposure. The highest RQ is below the LOC for mammals, but exceeds the endangered species LOC of 0.1 for cotton and pome fruit (Brugger, 1997).

Bees: In bees, indoxacarb is considered highly toxic by contact ([Table 2](#)) and practically non-toxic by dietary intake (U.S. EPA, 2000). DPX-MP062 is predicted to be highly toxic to bees, based on laboratory studies with DPX-JW062. Although the pesticide is highly toxic to honeybees upon direct contact, DuPont states that there is a low impact on honeybees after the spray has dried. For instance, a study of honeybees exposed to residues in alfalfa at the maximum proposed single use rate (0.11 a.i./acre) reported that bees were not affected after 3 hours post-application (Brugger, 1997). Although, additional field data show that DPX-MP062 sprayed at a rate of 133 g/hectare caused significant mortality after a 24-hour exposure (Hetrick et al., 2005).

Insects: Pesticide resistant insects can be a major problem for many crops resulting in the need for new chemistries such as indoxacarb. The cotton bollworm *Helicoverpa armigera*, a major pest in cotton, is highly resistant to several conventional pesticide chemistries, but was found to have only a three-fold tolerance to indoxacarb in Pakistan (Ahmad et al., 2003). The obliquebanded leafroller *Choristoneura rosaceana*, on the other hand, has been found to be highly resistant to indoxacarb in the U.S. even before its field use. This resistance is presumed to be due to cross-resistance to organophosphates (Ahmad et al., 2002). A high level of synergism by P450 inhibitor piperonyl butoxide (PBO) was found with indoxacarb, which reduced the resistance level of *C. rosaceana* (Ahmad and Hollingworth, 2004) and a New York indoxacarb-resistant (NYINDR) strain of house fly *Musca domestica* (Ahmad and Hollingworth, 2004; Shono et al., 2004). The NYINDR strain was produced in three generations from house flies that were never exposed to indoxacarb in the field indicating that resistance can be readily selected in house flies (Shono et al., 2004). Even though it is a new chemistry, it will be important to rotate chemistries and judiciously use indoxacarb to prevent resistant pests in the future.

Indoxacarb has been shown to be relatively safe for several orders of beneficial insects largely due to low dermal toxicity for the species tested (Michaud and Grant, 2003; Bostanian et al., 2004; Galvan et al., 2005a). While indoxacarb may have low acute toxicity to many predators at the suggested rates, and even reduced rates, it may reduce *Harmonia axyridis* population growth by affecting survival, development, and reproduction (Galvan et al., 2005b). At suggested rates, indoxacarb has been found to be toxic to the predacious mirid *Hyaliodes vitripennis* (Bostanian

et al., 2004), moderately toxic to coccinellids and somewhat toxic to *Orius insidiosus* nymphs (Musser and Shelton, 2003). When using indoxacarb as a part of an integrated pest management plan it will be important to identify the beneficial insects in the field and to determine if they are adversely affected by indoxacarb.

SUMMARY

Indoxacarb is a nonsystemic insecticide and is considered a "reduced risk" pesticide by U.S. EPA (U.S. EPA, 2000). This insecticide is used to control sucking and chewing insects and is especially effective on Lepidoptera. The insecticidal activity occurs by blocking the sodium channels in the insect nervous system and the mode of entry is via the stomach and contact routes resulting in impaired nerve function, feeding cessation, paralysis, and death. Indoxacarb is primarily used in agriculture although home use products are becoming more available.

The pesticide is relatively non-volatile with a low vapor pressure and a low Henry's law constant. Consequently, volatilization is not a significant factor in dissipation. The low water solubility, high K_{ow}, and moderately high K_{oc} suggest that indoxacarb will have a moderate to strong tendency to partition from water to soil and therefore be relatively immobile in soil. Several of the degradation products have low K_{oc} values but the degradates with the lowest K_{oc} values also had the slowest degradation rates. Hydrolysis is an important degradation route at alkaline or neutral pH, but much less important under more acidic conditions. In vegetation, indoxacarb does not appear to have an adverse effect on non-target terrestrial plants. Indoxacarb is moderately to very highly toxic to freshwater, estuarine/marine fish and insects. In bees, it is highly toxic by contact, but may have lesser post-application toxicity after drying on vegetation. Indoxacarb has an exceptionally complex degradation profile with two degradation products, IN-JT333 and IN-MP819, expected to exhibit ecotoxic effects. Indoxacarb has a relatively low potential for leaching and runoff/erosion due to its high sorption coefficient, rapid rate of degradation in soil, and relatively low use rate. In conclusion, based on these fate properties indoxacarb appears to have a relatively low potential for significant offsite movement at concentrations that would cause environmental effects.

REFERENCES

Ahmad, M., M.I. Arif, and A. Ahmad. 2003. Susceptibility of *Helicoverpa armigera* (Lepidoptera: Noctuidae) to new chemistries in Pakistan. Crop Prot. 22:539-544.

Ahmad, M. and R.M. Hollingworth. 2004. Synergism of insecticides provides evidence of metabolic mechanisms of resistance in the obliquebanded leafroller *Choristoneura rosaceana* (Lepidoptera: Tortricidae). Pestic. Manag. Sci. 60:465-473.

Ahmad, M., R.M. Hollingworth, and J.C. Wise. 2002. Broad-spectrum insecticide resistance in obliquebanded leafroller *Choristoneura rosaceana* (Lepidoptera: Tortricidae) from Michigan. Pestic. Manag. Sci. 58:834-838.

Berg, D.S. 1997. Photodegradation of radiolabeled DPX-JW062 (a racemic mixture of DPX-KN128 and IN-KN127) on soil under simulated sunlight. DuPont Report No. AMR 2818-93. E. I. du Pont de Nemours and Company, Wilmington, DE.

Bonino, B., J.C. Rühl, and B.P. Smyser. 1999. Field soil dissipation of DPX-JW062 (racemic mixture of DPX-128 [insecticidally active enantiomer] and IN-KN127) following application of DPX-JW062 experimental insecticide to bare ground. DuPont Report No.
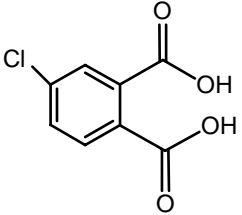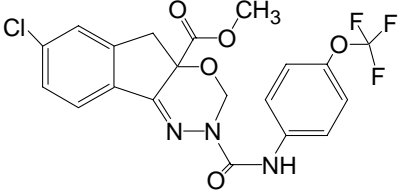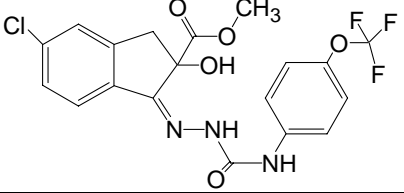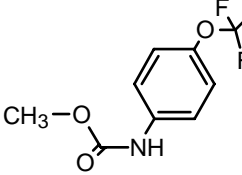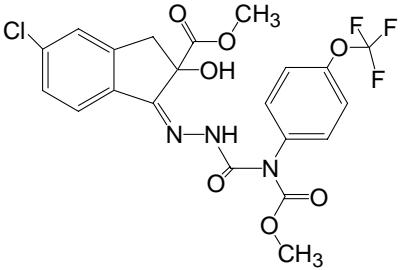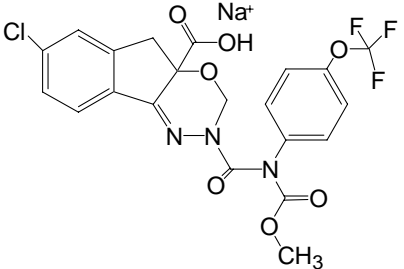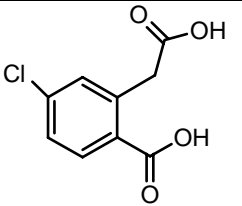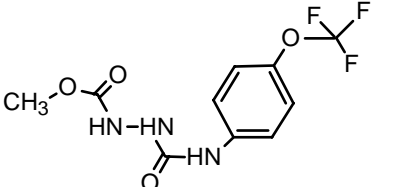
AMR 3402-95 Supplement No. 1. E. I. du Pont de Nemours and Company, Wilmington, DE.

Bostanian, N.J., C. Vincent, J.M. Hardman, and N. Larocque. 2004. Toxicity of indoxacarb to two species of predacious mites and a predacious Mirid. Pest Manag. Sci. 60:483-486.

Brown, A.M. and G.A. Young. 1997. Metabolism of [TMP(U)-^{14}C]DPX-JW062, a racemic mixture of DPX-KN128 and IN-KN127, insecticide in tomatoes. DuPont Report No. AMR 3561-95. E. I. du Pont de Nemours and Company, Wilmington, DE.

Brugger, K.E. 1997. DPX-MP062: Prospective tier I ecological effects assessment for non-target organisms. DuPont Report No. AMR 4782-97. E. I. du Pont de Nemours and Company, Wilmington, DE.

California Department of Pesticide Regulation. 2006. Summary of pesticide use report data 2004 *Indexed by chemical*. CDPR, Sacramento, CA.

California Department of Pesticide Regulation. 2005a. DPR Product/Label Database. Pesticide Registration Branch. CDPR, Sacramento, CA.

California Department of Pesticide Regulation. 2005b. DPR Pesticide Use Report Database. Enforcement Branch. CDPR, Sacramento, CA.

California Department of Pesticide Regulation. 2005c. DPR Pesticide Chemistry Database. Environmental Monitoring Branch. CDPR, Sacramento, CA.

Caldwell, E. 2002. Adsorption/Desorption of [C^{14}]IN-MK643, a metabolite of indoxacarb, in five soils. DuPont-9784. E. I. du Pont de Nemours and Company, Wilmington, DE.

Campbell, S., L. Chen, J. Yu, and Q.X. Li. 2005. Adsorption and analysis of the insecticides thiamethoxam and indoxacarb in Hawaiian soils. J. Agric. Food. Chem. 53:5373-5376.

Cobranchi, D.P. and M.E. Schmuckler. 1997. Vapor pressure of DPX-KN128 and calculation of Henry's law constant. DuPont Report No. AMR 4169-96. E. I. du Pont de Nemours and Company, Wilmington, DE.

Crop Protection Handbook. 2003. Meister Publishing Company. Vol. 89 (89th ed.) C 274. Willoughby, OH.

DuPont. 2006. Section 3 specimen label-CA. [Online]. Available at http://www.dupont.com/ag/us/prodinfo/prodsearch/information/H64922.pdf. (Verified May 11, 2006). E. I. du Pont de Nemours and Company, Wilmington, DE.

Ferraro, P., and S.F. McEuen. 1996. Hydrolysis of DPX-JW062 (a racemic mixture of DPX-KN128 and DPX-KN127) in buffer solutions of pH 5, 7, and 9. DuPont Report No. AMR 2789-93. E. I. du Pont de Nemours and Company, Wilmington, DE.

Ferraro, P., and S.F. McEuen. 1997. Photodegradation of DPX-JW062 (a racemic mixture of DPX-KN128 and IN-KN127) in pH 5 buffer solution and natural water by simulated sunlight. DuPont Report No. AMR 2788-93. E. I. du Pont de Nemours and Company, Wilmington, DE.

Fetterman, D.E, and R.L. Chrzanowski. 1997. Soil column leaching study of C-DPX-MP062 (a 3:1 mixture of DPX-KN128 and IN-KN127) on four aged soils. DuPont Report No. AMR 3845-96. E. I. du Pont de Nemours and Company, Wilmington, DE.

Gaddamidi, V. and B.M. Hashinger, II. 1997. Metabolism of [^{14}C]DPX-JW062, a racemic mixture of DPX-KN128 and IN-KN127 in lettuce. DuPont Report No. AMR 2730-93. E. I. du Pont de Nemours and Company, Wilmington, DE.

Galvan, T.L., R.L. Koch, and W.D. Hutchison. 2005a. Toxicity of commonly used insecticides in sweet corn and soybean to multicolored Asian lady beetle (Coleoptera: Coccinellidae). J. Econ. Entomol. 98:780-789.

Galvan, T.L., R.L. Koch, and W.D. Hutchison. 2005b. Effects of spinosad and indoxacarb on survival, development, and reproduction of the multicolored Asian lady beetle (Coleoptera: Coccinellidae). Biol. Control 34:108-114.

Hatzenbeler, C.J. 2002a. Adsorption/Desorption of [C^{14}]IN-JU873, a metabolite of indoxacarb, in five soils. DuPont-6407. E. I. du Pont de Nemours and Company, Wilmington, DE.

Hatzenbeler, C.J. 2002b. Adsorption/Desorption of [C^{14}]IN-KG433 in five soils. DuPont-6408, Revision No.2. E. I. du Pont de Nemours and Company, Wilmington, DE.

Herczog, K.J.S. 2002. Adsorption/Desorption of [^{14}C]IN-MK638, a metabolite of indoxacarb in five soils. DuPont-10279. E. I. du Pont de Nemours and Company, Wilmington, DE.

Hetrick, J, W. Evans, and S. Abel. 2005. Environmental Fate and Effects Division risk assessment for proposed new uses of indoxacarb on grapes, fire ants, mole crickets, alfalfa, peanut, soybeans, Brassica leafy vegetables (Group 5), and turnip greens. PC Code 067710. U.S. EPA, Washington, D.C.

Kannuck, R.M. and K.E. Brugger. 1997. Tier 1 environmental risk assessment of DPX-MP062 and competitive insecticides in the USA. DuPont Report No. AMR 4635-97. E. I. du Pont de Nemours and Company, Wilmington, DE.

Kubiak, R. 1996. Investigation of the volatilization of [^{14}C]-DPXJW062 from plant and soil surfaces under laboratory conditions. DuPont Report No. AMR 3711-95. E. I. du Pont de Nemours and Company, Wilmington, DE.

Lentz, N. 2002a. Hydrolysis of ^{14}C-DPX-MP062 in buffer solutions of pH 5, 7, and 9. DuPont-9800. E. I. du Pont de Nemours and Company, Wilmington, DE.

Lentz, N. 2002b. Photodegradation of ^{14}C-DPX-MP062 in pH 5 buffer by simulated sunlight. DuPont-9801. E. I. du Pont de Nemours and Company, Wilmington, DE.

Mellor, S. 2003. ^{14}C-DPX-MP062 (a 3:1 mixture of DPX-KN128 and IN-KN127): Aerobic soil metabolism. DuPont-8516. E. I. du Pont de Nemours and Company, Wilmington, DE.

Michaud, J.P. and A.K. Grant. 2003. IPM-compatibility of foliar insecticides for citrus: Indices derived from toxicity to beneficial insects from four orders. J. Insect Sci. 3:1-10. [Online]. Available at http://insectscience.org/3.18/. (Verified May 12, 2006).

Musser, F.R. and A.M. Shelton. 2003. Bt sweet corn and selective insecticides: Impacts on pests and predators. J. Econ. Entomol. 96:71-80.

Rhodes, B.C. 1997. Aerobic soil metabolism of ^{14}C-DPX-JW062. DuPont Report No. AMR 2803-93. E. I. du Pont de Nemours and Company, Wilmington, DE.

Rühl, J.C. 1997. Field soil dissipation of [^{14}C]DPX-JW062 (racemic mixture of DPX-KN128 and IN-KN127) following application of DPX-JW062 experimental insecticide. DuPont Report No. AMR 3400-95 Revision No. 1. E. I. du Pont de Nemours and Company, Wilmington, DE.

Russell, M.H. 2004. Revised kinetic calculations of DPX-MP062 and metabolites in laboratory soil and water studies following FOCUS guidance. DuPont-14984, Revision No. 1. E. I. du Pont de Nemours and Company, Wilmington, DE.

Russell, M.H. 1997. Calculation of potential concentrations of DPX-MP062 in ground water and surface water. DuPont Report No. JW062/ENV2. E. I. du Pont de Nemours and Company, Wilmington, DE.

Scott, M.T. and J.C. Guseman. 1997. Metabolism of ^{14}C-DPX-JW062, a racemic mixture of DPX-KN128 and IN-KN127, in cotton. DuPont Report No. AMR 2691-93. E. I. du Pont de Nemours and Company, Wilmington, DE.

Shaw, D. 2002. ^{14}C-DPX-MP062 (a 3:1 mixture of DPX-KN128 and IN-KN127): Degradability and fate in the water/sediment system. DuPont-8417. E. I. du Pont de Nemours and Company, Wilmington, DE.

Shono, T., L. Zhang, and J.G. Scott. 2004. Indoxacarb resistance in the house fly, *Musca domestica*. Pestic. Biochem. Physiol. 80:106-112.

Silver, K.S., and D.M. Soderlund. 2005. Action of pyrazoline-type insecticides at neuronal target sites. Pestic. Biochem. Physiol. 81:136-143.

Singles, S.K. 2002a. Rate of degradation and estimated K_{oc} of IN-ML438 in soil. DuPont-11433. E. I. du Pont de Nemours and Company, Wilmington, DE.

Singles, S.K. 2002b. Aerobic metabolism of ^{14}C-DPX-JW062. DuPont Report No. AMR 2803-93, Revision 1. E. I. du Pont de Nemours and Company, Wilmington, DE.

Singles, S.K. 2004. Overview of the environmental fate of DPX-MP062 in soil and aquatic systems. DuPont-15311. E. I. du Pont de Nemours and Company, Wilmington, DE.

Smyser, B.P. 2002a. Anaerobic aquatic metabolism of [indanone-1-^{14}C]DPX-JW062 and [trifluoromethoxyphenyl(U)-^{14}C]DPX-JW062, a racemic (50:50) mixture of DPX-KN128 and IN-KN127. DuPont Report No. AMR 3236-94, Revision No. 2. E. I. du Pont de Nemours and Company, Wilmington, DE.

Smyser, B.P. 2002b. Field soil dissipation of [^{14}C]DPX-JW062 (racemic mixture of DPX-KN128 and IN-KN127) following application of DPX-JW062 experimental insecticide.

DuPont Report No. AMR 3400-95, Supplement No. 2. E. I. du Pont de Nemours and Company, Wilmington, DE.

Smyser, B.P. 2002c. Batch equilibrium study of DPX-JW062 (a racemic mixture of DPX-KN128 and IN-KN-127) and IN-JT333. DuPont Report No. AMR 3489-95, Rev. 1. E. I. du Pont de Nemours and Company, Wilmington, DE.

Spare, W.C. 1997. Aerobic soil metabolism of DPX-MP062, an ≈3:1 mixture of DPX-KN128 and IN-KN127. DuPont Report No. AMR 3633-95. E. I. du Pont de Nemours and Company, Wilmington, DE.

Tsurubuchi, Y., and Y. Kono. 2003. Modulation of sodium channels by the oxadiazine insecticide indoxacarb and its *N*-decarbomethoxylated metabolite in rat dorsal root ganglion neurons. Pest. Manag. Sci. 59:999-1006.

U.S. EPA. 2000. Pesticide fact sheet: Indoxacarb. U.S. EPA, Washington, DC.

U.S. EPA. 2004. Indoxacarb; time-limited pesticide tolerance. Fed. Regist. 69:28832-28842. U.S. EPA, Washington, DC.

U.S. EPA. 2006. SCI-GROW Description. [Online]. Available at http://www.epa.gov/oppefed1/models/water/scigrow_description.htm. (Verified July 20, 2006). U.S. EPA, Washington, DC.

Vincent, D.R., K.T. McCooey, and J.C. Rühl. 1997. Field soil dissipation of DPX-JW062 (racemic mixture of DPX-128 [insecticidally active enantiomer] and IN-KN127) following application of DPX-JW062 experimental insecticide to bare ground. DuPont Report No. AMR 3402-95. E. I. du Pont de Nemours and Company, Wilmington, DE.

Walsh, K.J. 2003. Adsorption/Desorption of [C^{14}]IN-KT413, a metabolite of indoxacarb, in four soils. DuPont-10500. E. I. du Pont de Nemours and Company, Wilmington, DE.

Wing, K.D., M. Sacher, Y. Kagaya, Y. Tsurubuchi, L. Mulberig, M. Connair, and M. Schnee. 2000. Bioactivation and mode of action of the oxadiazine indoxacarb in insects. Crop. Prot. 19:537-545.

Wing, K.D., M.E. Schnee, M. Sacher, and M. Connair. 1998. A novel oxadiazine insecticide is bioactivated in Lepidopteran larvae. Arch. Insect Biochem. Physiol. 37: 91-103.

Zhao, X., T. Ikeda, J.Z. Yeh, and T. Narahashi. 2003. Voltage-dependent block of sodium channels in mammalian neurons by the oxadiazine insecticide indoxacarb and its metabolite DCJW. NeuroToxicology 24:83-96.

Figure 1. Degradation products of indoxacarb.

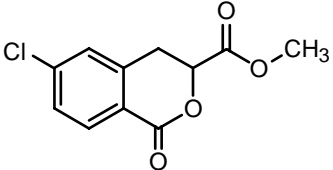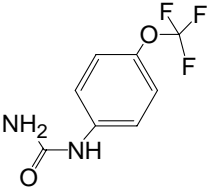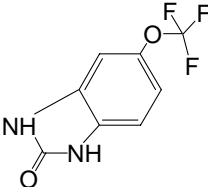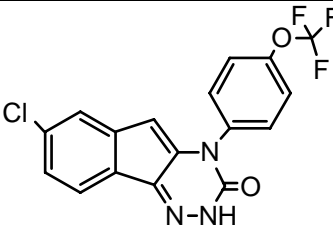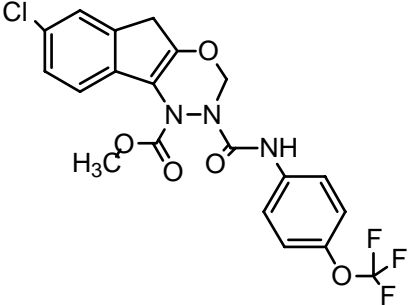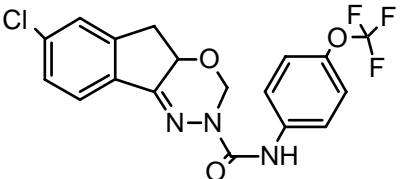|	
IN-C0639 CAS name: not available	
IN-JT333 CAS name: methyl 7-chloro-2,5-dihydro-2-[[[4-(trifluoromethoxy) phenyl]amino]carbonyl]indeno[1,2-e][1,3,4]oxadiazine-4a(3*H*)-carboxylate	
IN-JU873 CAS name: methyl 5-chloro-2,3-dihydro-2-hydroxy-1-[[[[4-trifluoromethoxy)phenyl]amino]carbonyl]hydrazono]-1H-indene-2-carboxylate	
IN-KB687 CAS name: methyl [4-(trifluoromethoxy)phenyl]carbamate	
IN-KG433 CAS name: methyl 5-chloro-2,3-dihydro-2-hydroxy-1-[[[(methoxycarbonyl)[4-(trifluoromethoxy)phenyl]amino]carbonyl]hydrazono]-1*H*-indene-2-carboxylate	
IN-KT413 CAS name: sodium 7-cholor-2,5,-dihydro-2-[[methoxycarbonyl)[4(trifluoromethoxy)phenyl]amino]carbonyl]indeno[1,2-e][1,3,4]oxadiazine-4a(3H)-carboxylic acid	
IN-MA573 CAS name: not available	
IN-MF014 CAS name: methyl 2-[[[4(trifluoromethoxy)phenyl]amino]carbonyl]hydrazine carboxylate	

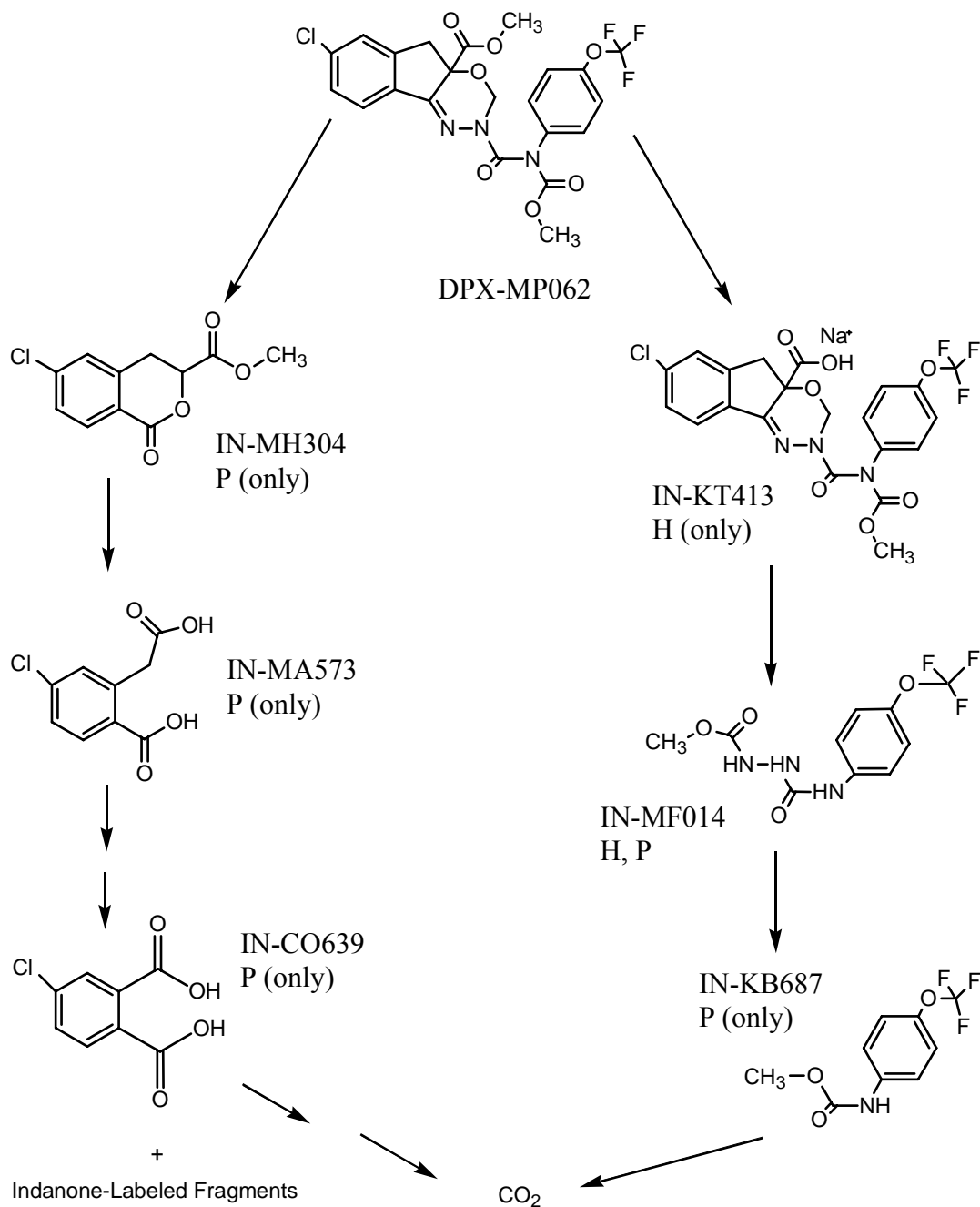|	
IN-MH304 CAS name: methyl 6-chloro-3,4-dihydro-1-oxo-1H-2-benzopyran-3-carboxylate	
IN-MK638 CAS name: [4-(trifluoromethoxy)phenyl]urea	
IN-MK643 CAS name: 1,3-dihydro-5-(trifluoromethoxy)-2H-benzimidazol-2-one	
IN-ML438 CAS name: 7-chloro-2,4-dihydro-4-[4 (trifluoromethoxy)phenyl]3H-indeno[2,1-e]-1,2,4-triazin-3-one	
IN-MP819 CAS name: not available	
IN-MS775 CAS name: not available	

Figure 2. Proposed hydrolysis and aqueous photolysis degradation pathway for DPX-MP062. Redrawn from Singles (2004).

DPX-MP062

IN-MH304
P (only)

IN-KT413
H (only)

IN-MA573
P (only)

IN-MF014
H, P

IN-CO639
P (only)

IN-KB687
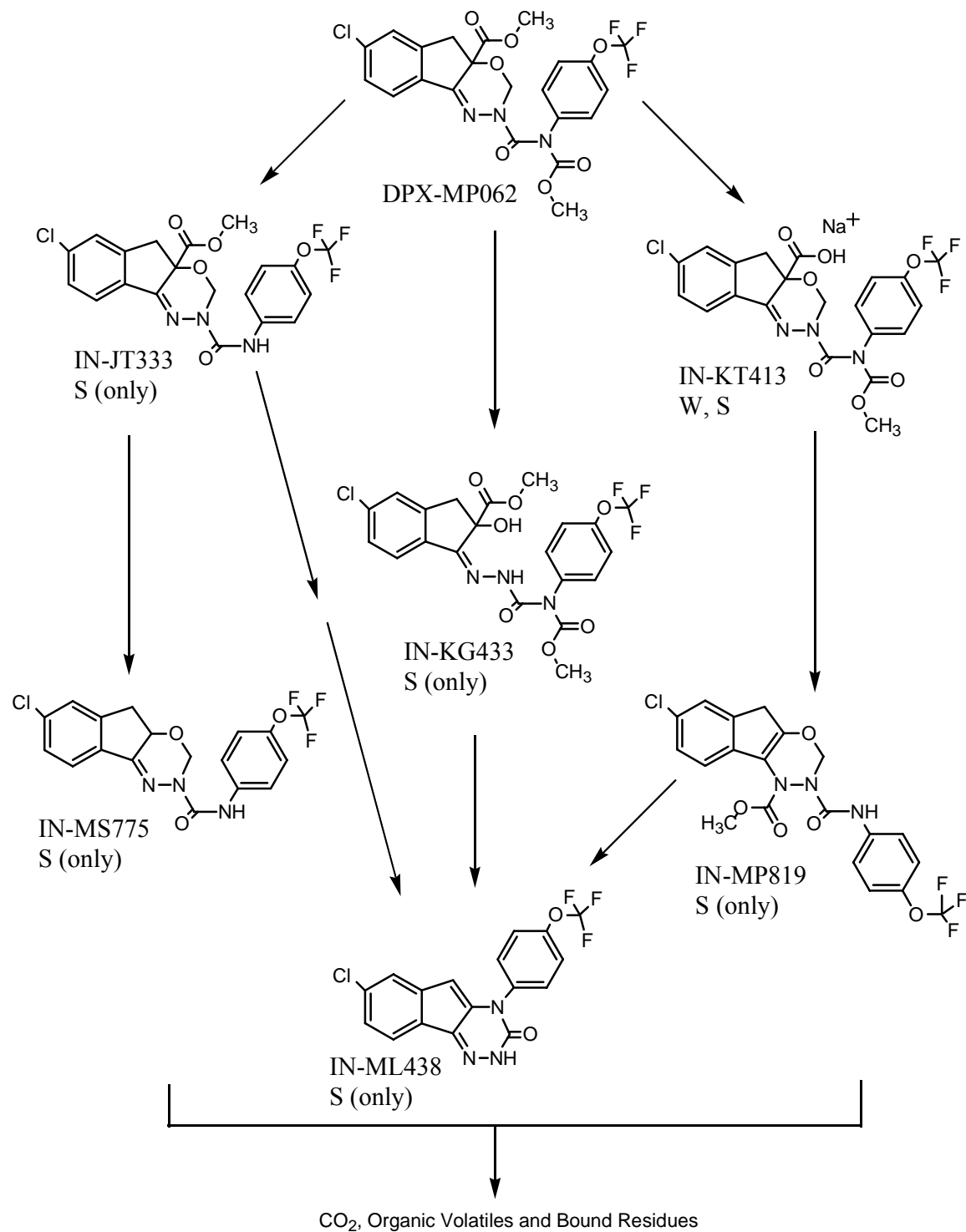P (only)

+

Indanone-Labeled Fragments

CO_2

Key:
H: Hydrolysis
P: Aqueous Photolysis

Figure 3. Proposed degradation pathway for DPX-MP062 in water/sediment systems. Redrawn from Singles (2004).

DPX-MP062

IN-JT333
S (only)

IN-KT413
W, S

IN-KG433
S (only)

IN-MS775
S (only)

IN-MP819
S (only)

IN-ML438
S (only)

CO_2, Organic Volatiles and Bound Residues

Key:
W: Water Phase
S: Sediment

Figure 4. Proposed degradation pathway of DPX-MP062 in aerobic soil. Redrawn from Singles (2004).